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With this volume, I am very pleased to report that the Journal of the Entomological Society has more or less completed its transformation to electronic publication. Moving JESO to this point has been my major objective as Editor, and it is very satisfying to have achieved this goal. Perhaps you are already aware that pre-print PDF versions of manuscripts are now being posted on the JESO website soon after final revisions are accepted. We intend to keep publishing paper copies of the Journal once per year, and so for the foreseeable future, this is the last change we are planning to make to our publication process. Electronic pre-publication significantly speeds up the process of disseminating our contributors' research, which is one major benefit of this next step.

Another significant step forward is underway with updating of the JESO website. For the past year or so, I have periodically tested Google's ability to find published manuscripts on the JESO website. The results were disappointing – until now. Recently, JESO's profile was updated in a web-based database of scientific journals, and an almost immediate consequence was that JESO is now much more visible to electronic search engines such as Google. In other words, not only are JESO manuscripts now quickly available for dissemination, but they should become steadily more visible to entomologists around the world.

As always, the research presented in Volume 140 (2009) covers a range of entomological topics and methodologies. JESO is a particularly appropriate journal for publication of new faunal records, and this volume continues that tradition. A theme of several papers in this volume is predator-prey interactions, the prey comprising plants or animals. It is interesting how much entomology focuses on the causes and consequences of insect dining, for insects, for the natural world, and of course, for ourselves. This volume also includes a special reviewed essay on the shared history of the ESO and the ESC, one of a series of essays that we hope to publish in the several years leading up to the 150th anniversary of the society.

Happy reading!

Miriam H. Richards  
Editor





## ON THE DURATION AND DISTRIBUTION OF FOREST TENT CATERPILLAR OUTBREAKS IN EAST-CENTRAL CANADA

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### Abstract

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An analysis of forest tent caterpillar (*Malacosoma disstria* Hbn.) defoliation records from Ontario and Quebec indicates that outbreaks recur periodically and somewhat synchronously ( $r = 0.51$ ) in the two provinces, with six inter-provincial-scale cycles having been observed over the period 1938-2002. When the entire spatiotemporal range of observed defoliation is considered, it appears that, at the local stand level, individual outbreaks tend to last for less than a year on average. Within the three core areas where all six cycles were observed (Dryden, Sudbury, Temiscamingue), individual outbreaks tended to last for  $2.6 \pm 0.5$  years. The seemingly small difference between two versus three years of detectable defoliation at the local stand level appears to be critical, as this determines whether annual rates of stem mortality are sufficient to produce obvious signs of forest decline. Infestations lasting three years or longer normally occur in ~45% of the stands within the relatively small core outbreak areas. However not all infestations behave “normally”, in the sense of being the product of a regionally synchronized population cycle. For example, we show how a reversing, traveling wave of forest tent caterpillar outbreaks in northern Ontario in the 1990s generated an unusually long-lasting infestation along the Highway 11 corridor – an outbreak which resulted in a regional-scale decline of trembling aspen. This demonstrates how incomplete synchronization of forest insect population cycles can lead to overlapping waves of outbreak that may result in large-scale forest disturbance.

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## Introduction

The forest tent caterpillar, *Malacosoma disstria* Hbn., is a voracious defoliator of hardwood trees throughout North America, exhibiting large-scale, periodic outbreaks on trembling aspen, *Populus tremuloides* Michx., in much of the boreal forest (Witter 1979). During a typical outbreak, detectable defoliation persists for one to many years, with the total length of outbreak varying both spatially, within an outbreak, and temporally, among outbreaks. Different authorities, reporting from different areas and over different time periods, have provided different estimates of the average duration of outbreak (Table 1); however, it is not clear why these estimates vary.

Outbreak duration undoubtedly varies among outbreaks and among jurisdictions. However estimates also vary depending on the way the subjective term ‘outbreak’ is defined. Sippell (1962), for example, pointed out that although the province-wide outbreak of 1948-56 in Ontario spanned “a period of nine years”, infestations within “individual stands” tended to exhibit only “one or two years” of “population excess”. Because local infestations do not all occur at exactly same time among stands across the province, “infestations” (i.e. local-scale outbreaks), by definition, do not last as long as landscape-scale “outbreaks”. At the limit, when infestation occurrence is highly asynchronous, it becomes impossible to discern individual outbreaks – a situation which caused Hildahl and Reeks (1960) to reject the idea of forest tent caterpillar population cycling in west-central Canada.

The purpose of this paper is to provide a transparent and statistically robust answer to the question: “how long do forest tent caterpillar outbreaks tend to last?” – a question that is asked by thousands of communities each decade across the country. For example, this is the question currently being asked in Georgetown, P.E.I., where, after two consecutive years of heavy defoliation, local residents and authorities are seeking a precise answer as to the expected termination date, along with some idea of the degree of uncertainty surrounding this estimate.

To the individual on the ground who has already witnessed a year or two of severe defoliation, there is a major difference between an expected duration of “one or two years” of outbreak versus “three or more years”. The variability and lack of specified precision in the estimates in Table 1 is therefore disconcerting. The tendency in the literature to characterize insect disturbance regimes in terms of their long-term, regional-scale behaviour – though understandable from a population dynamics perspective – is not particularly helpful to the individual landowner or stand-level forester facing the “here and now” of an outbreak crisis situation. Forest tent caterpillars are capable of bringing about the decline of trembling aspen trees and stands over large areas (Churchill et al. 1964, Candau et al. 2002, Hogg et al. 2002). So the penultimate question of interest to all parties concerned is how long outbreaks tend to last at the level of individual trees and stands.

Of particular concern is the fact that the outbreak duration estimates in Table 1 are all higher than the figures calculated by Simpson and Coy (1999), who summarized defoliation records in the various forest regions of Canada over the relatively short time frame 1980-1996 (Fig. 1). Their analysis suggested that the three major forest regions were quite similar, in that 95% of all infestations last for three years or less – a result that seems to be at odds with the much longer estimates suggested in Table 1. Is this discrepancy just a function of Sippell’s (1962) stand vs. landscape scaling issue? Or is it because of a



mismatch in the time scales of observation? Clearly, the issue of outbreak duration is one that needs to be addressed using quantitative, scale-sensitive methods if these important discrepancies are to be resolved.

TABLE 1. Outbreak duration, estimated in a variety of ways across a range of jurisdictions, according to several authors. In some cases detailed estimation methods are given in the original source. In others the estimate is based on informed opinion.

Authority	Jurisdiction	Duration (yrs)	Type of estimate
Cerezke & Volney 1995	Prairie provinces	3-6	qualitative
Witter 1979	Minnesota, USA	3-4	qualitative
Sippell 1962	Ontario	3-9	semi-quantitative
Roland 1993	eight districts in Ontario	1.7-3.3	quantitative

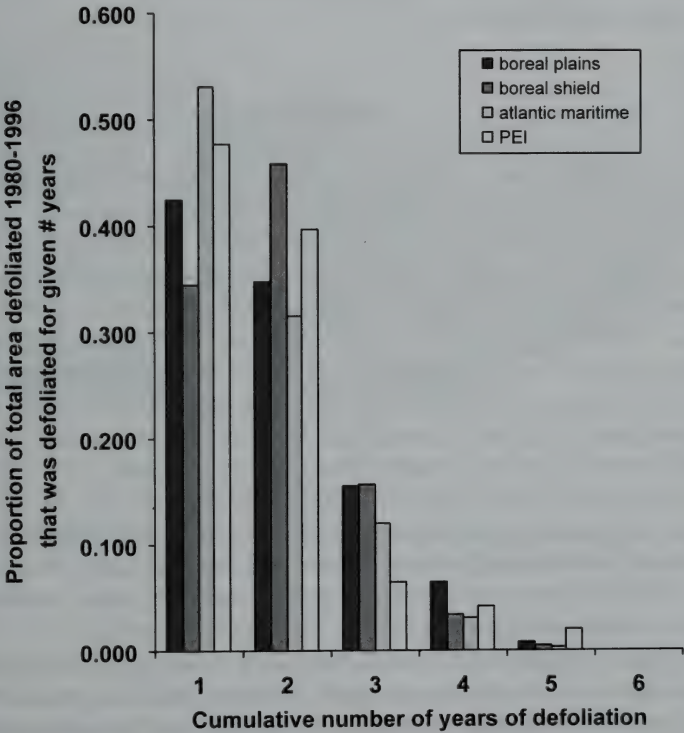


FIGURE 1. Outbreak duration in three major forest regions of Canada, according to Simpson and Coy's (1999) Table 4.

## Materials and Methods

We analysed the duration of forest tent caterpillar outbreaks over the seven decades for which Canadian Forest Insect and Disease Survey records exist for the provinces of Ontario and Quebec, an area which corresponds roughly to the “boreal shield” region reported on by Simpson and Coy (1999). The source data, described by Fleming et al. (2000) for Ontario and Cooke and Lorenzetti (2006) for Quebec, consist of digitally rasterized aerial survey sketch maps of areas exhibiting moderate to severe defoliation attributable to forest tent caterpillar. Spanning 65 years (1938-2002) and two of the country’s largest provinces, this is the largest-scale study to date of long-term tent caterpillar outbreak dynamics.

Since 1938 there have been six distinct inter-provincial-scale outbreak cycles in east-central Canada, with moderate to severe defoliation occurring at periodic intervals of 9-13 years (Cooke and Lorenzetti 2006, Cooke et al. 2007). For each outbreak cycle, the number of consecutive years of moderate to severe defoliation at a given “point” was summed, and plotted in a histogram. This variable is henceforth referred to as “local-scale outbreak duration”, and is intended to represent the average duration of outbreaks at the “stand” level. In actuality these “points” were cells in a data raster, each cell spanning 1 km<sup>2</sup> in Ontario and ~58 km<sup>2</sup> in Quebec, the coarser resolution of the Quebec data being a function of the way these defoliation maps were rasterized by the province at a resolution of 15 minutes of latitude and longitude.

## Results

Forest tent caterpillar outbreaks in Ontario and Quebec tend to exhibit similar periodic patterns of occurrence ( $r = 0.51$  between provincial time-series), with the extent of annual defoliation being more variable in Quebec (C.V. = 216%) than in Ontario (C.V. = 139%) (Fig. 2, top). In both provinces there are a few core locations where defoliation is much more frequent than in surrounding areas (Fig. 2, bottom).

A map of local-scale outbreak duration during each of the six inter-provincial outbreak cycles reveals that the number of consecutive years of defoliation is highly spatially variable, lasting anywhere from 0 to 9 years depending on location (Fig. 3). A duration of “zero years” may seem paradoxical. However this is a natural result of the fact that individual outbreaks in Ontario and Quebec tend to span only  $43 \pm 7\%$  (s.e.) and  $37 \pm 13\%$  (s.e.) of the insect’s total (i.e. 1938-2002) outbreak range (Fig. 3). In other words, during a typical 12 year long population/outbreak cycle, 60% of the stands located within the area amenable to outbreak, for some reason, will not experience moderate-to-severe defoliation. It is in this sense that a regionally defined outbreak event can be said to have a duration of zero years in some locales.

How, then, to characterize the distribution of the number of years of defoliation at a given location during a typical outbreak cycle? In particular, should the zero values from non-defoliated areas be included in the analysis, or should they be excluded, as in Simpson and Coy’s (1999) analysis (e.g. Fig. 1)? Excluding them would clearly bias the outbreak duration estimate upward.

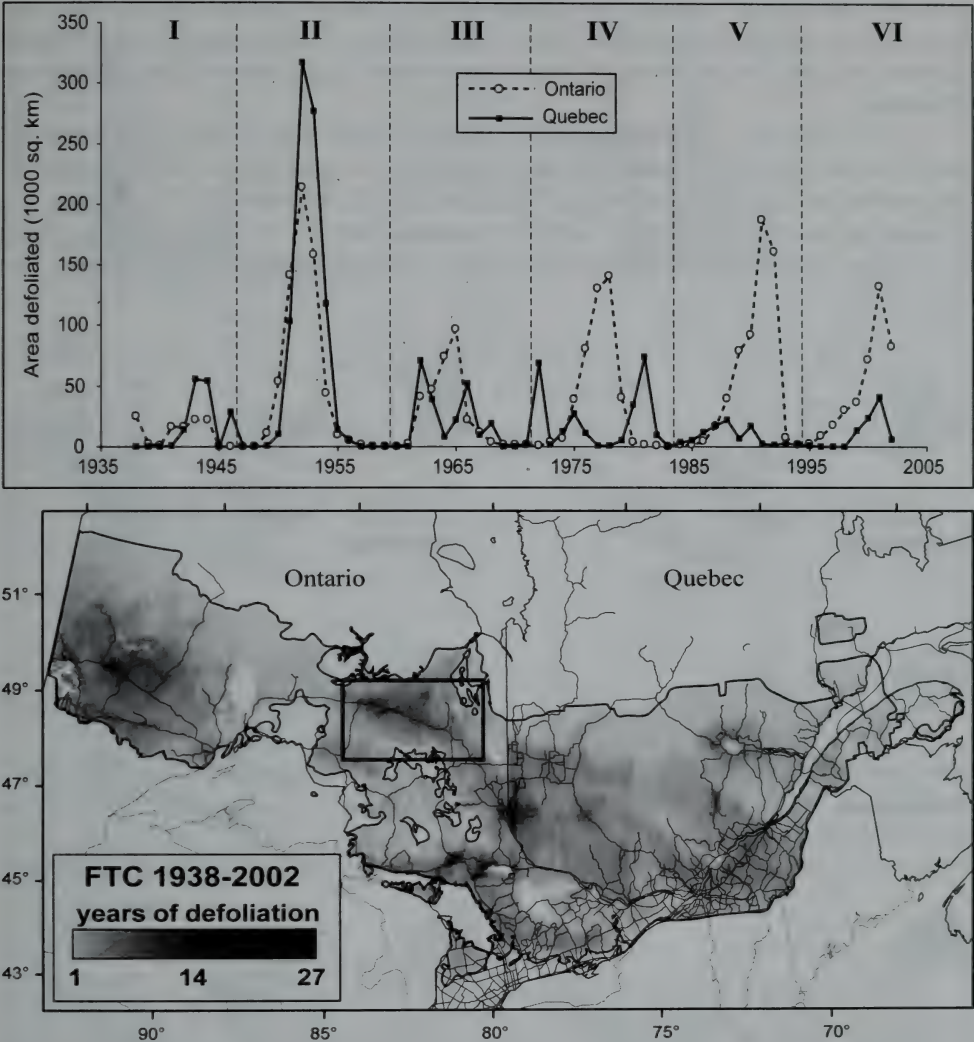


FIGURE 2. The distribution of forest tent caterpillar defoliation during six outbreak cycles in the provinces of Ontario and Quebec. Top: Outbreak cycles are fairly well synchronized between provinces, although cycles III, IV, and V appear to have been interrupted in the early stages of development in 1963, 1976, 1989 in Quebec, but not in Ontario. Bottom: Note the fairly seamless gradient across the Ontario-Quebec border, despite the different survey and data pre-processing methods. Road density (shown as dark lines) is broadly indicative of the degree of human settlement and forest fragmentation. Rectangle indicates area plotted in Fig. 6.



A second issue is spatial heterogeneity in outbreak frequency. Noting that defoliation in the Fig. 3 maps is most frequent in rural areas characterized by disturbed, semi-agricultural landscapes (Roland 1993), it would clearly be advantageous to distinguish between core areas where outbreaks are frequent *versus* fringe areas where outbreaks are infrequent.

The frequency distribution of the number of years that a given cell is defoliated during an outbreak cycle reveals that this variable is not unimodally distributed (Fig. 4). The number of zero values in these distributions is high, as expected for a random (i.e. Poisson) process with a low mean; however the spatial distribution of defoliation is clearly non-random, following a spatially autocorrelated gradient pattern (Fig. 3). Indeed, the

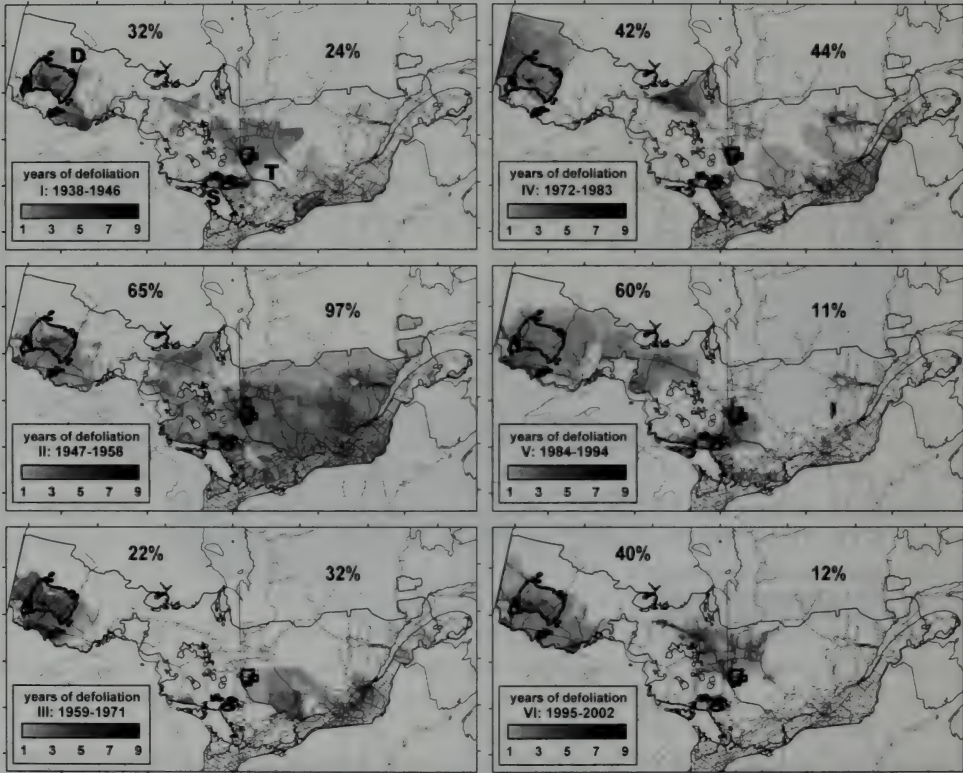


FIGURE 3. The distribution of forest tent caterpillar defoliation during each of six outbreak cycles in Ontario and Quebec. Thin and thick black outlines indicate (i) the entire outbreak range over the period 1938-2002 and (ii) the core areas where at least one year of defoliation occurred during each of all six cycles. Core areas labelled as “D” (Dryden), “S” (Sudbury), and “T” (Temiscamingue). The area between the thin and thick black outlines is referred to as the “fringe” area – the area where “zero values” for local outbreak duration are common. Percentages indicate the mean percentage of the outbreak range defoliated in each province during each cycle. Histograms of outbreak duration provided in Fig. 4.

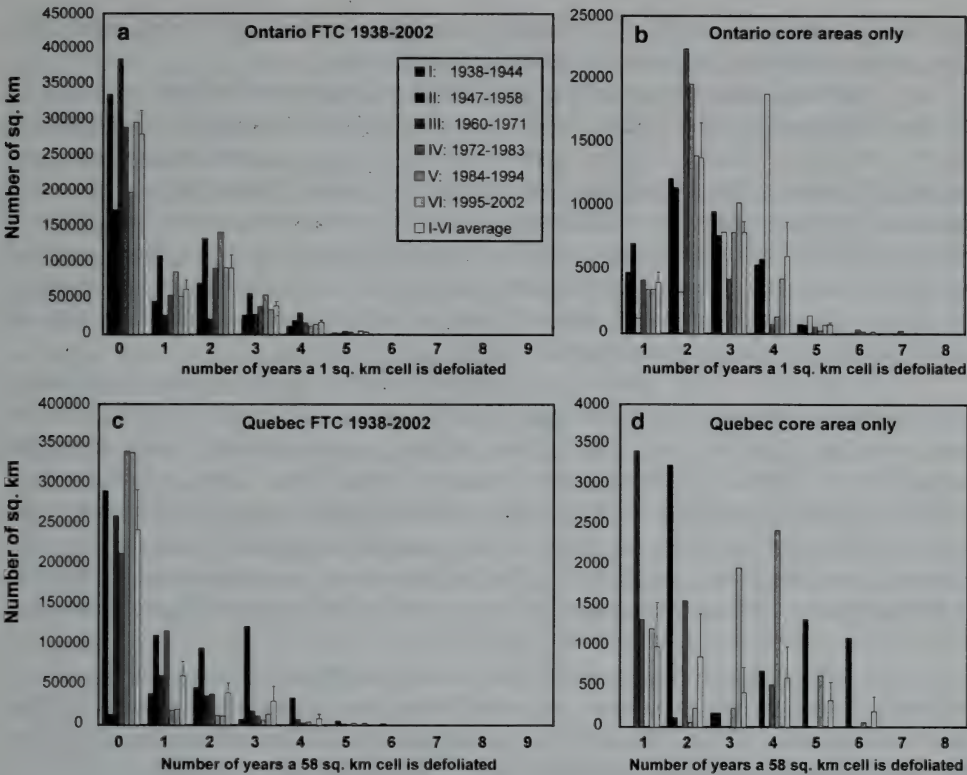


FIGURE 4. Frequency distribution of the number of years a given cell is defoliated during each of six outbreak cycles in Ontario (a,b) and Quebec (c,d), both across each province (a,c), and in “core” areas only (b,d), as defined in Fig. 3. The core area in northwestern Quebec is smaller than the core area in northwestern Ontario, and outbreak duration is much more variable among cycles.

TABLE 2. Average number of years of FTC defoliation expected during a “typical” outbreak cycle in a given cell in east-central Canada (based on  $n=6$  cycles, 1938-2002; data in Fig. 3). Condition “ $d \geq 3$ ” symbolizes the area experiencing three or more years of defoliation during a 12y outbreak cycle. Its relevance will become clear in Fig. 4. Note that these estimates include “zero values” – cells which were not defoliated during the (regionally defined) outbreak cycle. Also note that the core areas are areas which, by definition, did not exhibit any zero values during any outbreak cycle.

	Entire outbreak range			Core area only		
	mean $\pm$ s.e.	range	% area $d \geq 3$	mean $\pm$ s.e.	range	% area $d \geq 3$
Ontario	$0.92 \pm 0.11$	0-9	12.3	$2.58 \pm 0.47$	1-8	45.6
Quebec	$0.40 \pm 2.20$	0-9	10.4	$2.70 \pm 0.61$	1-6	45.5



bimodality in many of the Fig. 4 distributions suggests a composite distribution resulting from non-stationarity in the spatial distribution of outbreak.

Summary statistics of the mean and range of local-scale outbreak durations for the two provinces are provided in Table 2. Mean outbreak duration is comparable in the two provinces, although Quebec appears to offer a more variable environment, with outbreak duration exhibiting twice the variance as in Ontario. This is because the fringe area is estimated to comprise a much larger portion of the insect's range in Quebec than in Ontario. The higher variability in outbreak duration in Quebec appears to be exacerbated by the unusually large extent of defoliation during cycle II. Excluding cycle II from the calculation, the average extent of outbreaks relative to the total area amenable to outbreak would be  $39 \pm 6\%$  (s.e.) in Ontario and  $24 \pm 6\%$  (s.e.) in Quebec.

In the three "core" areas of northwestern Ontario (near Dryden), northeastern Ontario (near Sudbury), and northwestern Quebec (near L. Temiscamingue) outbreaks tend to last for  $2.6 \pm 0.6$  (s.e.) years. These are rural, populated areas where forest tent caterpillars are highly likely to encounter humans. In the "fringe" areas, which are more conifer-dominated, more remote, and are dominated by forest industry activity, outbreaks tend to last for only  $0.8 \pm 0.1$  (s.e.) years in Ontario, and less than this in Quebec. Reporting bias may therefore help to explain why the literature tends to overestimate the duration of outbreaks at something greater than two years: in conifer-dominated boreal landscapes there are fewer observers making fewer reports to fewer readers.

A key question is the probability that a given outbreak will persist for three years or longer. In both provinces, infestations lasting three years or longer will occur in  $\sim 11\%$  of the outbreak range. Within core areas where populations oscillate with regular periodicity, this figure jumps to  $\sim 45\%$  – still, less than half.

## Discussion

### 1. Duration of Outbreaks

Despite the large extent of forest tent caterpillar outbreaks in east-central Canada, 60% of the area theoretically available for defoliation does not actually experience any significant defoliation during a typical 12-year outbreak cycle. For the purposes of computing an average outbreak duration, it matters a great deal whether one chooses to include these "zero values" in the computation. In the "core" areas where all  $n=6$  outbreak cycles occurred this is a moot point because there are no such zero values. Beyond the "fringe" area there are nothing but zero values. If tent caterpillars can be found there, their populations never reach the level of causing aerially detectable defoliation. It is thus within the transition region of the fringe area that this question becomes relevant.

The quantitative estimate of outbreak duration by Roland (1993) in Table 1 included some of these zero values, in the sense that "if a specific township suffered no defoliation during an outbreak, this was included in the estimate of mean outbreak duration". However not all zero values were included because "populations were considered to be in the outbreak phase if there was moderate to severe defoliation recorded in at least one-third of the township", which means that the time-frame for summation was defined locally, not globally. Consequently there were many instances where the lack of defoliation in a



district prevented local zero values within a township ( $\sim 10 \times 10$  km) from being included in the district sum, despite the possible presence of significant and extensive defoliation in neighbouring districts. The qualitative estimates of outbreak duration provided in Table I probably tacitly exclude such zero values. If that is the case, it may help explain why these estimates appear to be biased high.

Given the contrasting data in Tables 1 and 2, we surmise that the estimates presented in Table 1 are descriptions of the dynamics of outbreaks in core areas where (1) outbreaks occur more frequently and more regularly, (2) the probability of people encountering mass aggregations of crawling larvae is highest, (3) forests are more fragmented and the local infestations that comprise the outbreak are not particularly well-synchronized across the landscape, and (4) forest entomologists interested in quantifying hardwood timber impacts were historically most likely to focus their attention.

Given the more objective and comprehensive analysis represented in Table 2, it would clearly be a distortion to suggest that infestations of three or more years in duration are in any way normal in east-central Canada. Authors who report an average outbreak duration of anything greater than three years – as in Table 1 – therefore must be reporting on the basis of individual infestations summed across a larger regional extent, which harkens back to Sippell's (1962) original comments on the relatively short duration of local-scale infestations compared to landscape-scale outbreaks, when individual infestations occur somewhat asynchronously.

In our case, choosing to focus on local-scale infestation dynamics means that our estimates of outbreak duration are not only bias-free, they also relate more closely to (i) the locally-acting processes that are thought to govern cycling (e.g. parasitism, predation, starvation, host-plant effects, disease) and (ii) the critical outcomes of concern (e.g. probability of permanent tree damage). Our estimates are thus useful to both the small private landowner and the large forest company.

Finally, the estimates reported here may well turn out to fit other regions, such as west-central Canada and the Atlantic maritime region, because they correspond well with the larger-scale, shorter-term estimates reported by Simpson and Coy (1999) in Fig. 1. Had we focused on landscape-level outbreak duration, this might not be the case, for it is well established that forest tent caterpillar outbreaks are less well synchronized in the prairie provinces (Hildahl and Reeks 1960) than in Ontario (Sippell 1962). By focusing on the duration of local-scale infestations, we effectively avoid the issue of the degree of synchrony among infestations within the area (and time-frame) of outbreak.

## 2. Forest-Insect Feedbacks

Roland (1993) was the first to attempt a quantitative analysis of the Ontario tent caterpillar data, and what he showed (using a smaller-scale, abbreviated dataset spanning cycles II-IV from 1948 to 1984) was that forest tent caterpillar outbreaks in eight major forest districts tended to last for 2.2 years on average, consistent with what is reported here for core areas of outbreak. He further showed that there tended to be a split in outbreak duration, with outbreaks in districts where forests were heavily fragmented lasting “4 to 6 years” and outbreaks in districts where forests were intact lasting only “one or two years”. A formal analysis indicated that just a single km of edge per square kilometre of forest area would increase the expected duration of outbreaks from 1.8 years to 2.7 years (see

his Fig. 2). Consistent with the Ontario data, where there is a strong association between aspen defoliation and the presence of major roads (Cooke and Roland 2000), we see in Fig. 2 a similar association in the province of Quebec – especially in the northwestern region around L. Temiscamingue. Moreover, the association between disturbance and prolonged outbreaks during cycles II-IV (Roland 1993) also appears to be present during cycles I, V, and VI (Fig. 3). The relationship between forest fragmentation and outbreak duration thus appears to be quite robust.

From a forestry perspective, the foregoing analysis becomes highly significant when one considers the result of Churchill et al. (1964), who showed that among dominant, co-dominant and intermediate (i.e. non-suppressed) trees, mortality due to “an unidentifiable agent” tended to increase sharply (from 10% to 30%) as the number of years of defoliation by forest tent caterpillars increased from two to three years of heavy defoliation (Fig. 5). These authors concluded that the unidentified killing agent must have been the delayed action of forest tent caterpillar defoliation occurring during the 1950s. Notably, caterpillar-caused mortality did not happen immediately after the outbreak had started or ended (Duncan and

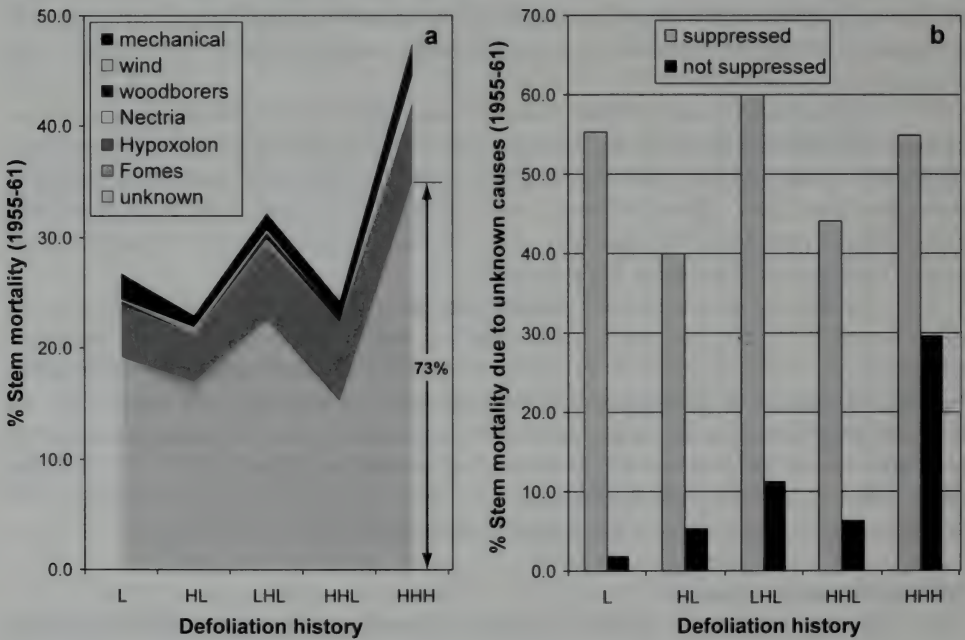


FIGURE 5. Aspen mortality in Minnesota occurring as a result of the 1951-59 forest tent caterpillar outbreak cycle (original data in Churchill et al. 1964). ‘L’ indicates a single year of light defoliation. ‘HHH’ indicates three consecutive years of heavy defoliation. (a) 73% of all mortality in the ‘HHH’ category is a result of “unknown” causes (i.e. delayed effects of forest tent caterpillar defoliation). (b) Trees that were “not suppressed” (all dominant, co-dominant and intermediate trees in the stand) show a clear response to defoliation intensity over time.



Hodson 1958), but occurred gradually, and in association with the growing abundance of a number of ancillary secondary agents. As time passed, the level of mortality became increasingly statistically significant and increasingly visually detectable. This is a pattern that has also been observed in western Canada (Hogg et al. 2002).

Putting the Roland (1993) and Churchill et al. (1964) results together, one may conclude that a single unit of forest fragmentation (one km forest edge per square km of forest area) can increase the probability that defoliation will intensify from 1.8 years of outbreak to 2.7 years of outbreak, which, based on Fig. 5b, would imply a two-fold increase in mortality among dominant stems, from ~12% to ~30%. In summary, although it is extremely uncommon for moderate-to-severe defoliation to last as long as 3 years or more in a given stand, (1) it clearly can happen, (2) forest fragmentation significantly increases the probability that the three-year threshold is crossed, and (3) the crossing of the three-year threshold implies significant tree mortality<sup>1</sup>. From this we conclude that not only are forest tent caterpillars quite capable of killing their primary host, trembling aspen, but the probability of heavy mortality increases with forest fragmentation. Notably, this implies a closed feedback loop between the effect of forest structure on insect dynamics, and the reciprocal impact of insects on the forest – a relationship that has been confirmed for two other major Canadian defoliators: the jack pine budworm (Nealis et al. 2003) and the spruce budworm (Nealis and Régnière 2004).

### 3. Overlapping Traveling Waves of Outbreak

Candau et al. (2002) suggested that forest tent caterpillars may have been the primary cause of more than 500 000 hectares of declining aspen along Trans-Canada Highway 11 in northern Ontario – an area where defoliation historically occurs rather frequently (Fig. 2, bottom). These authors showed that outbreak cycles V and VI in this region happened to occur in very close temporal proximity to one another, with consecutive outbreak peaks separated by six years, instead of ten years, which is the provincial norm (Fig. 2, top). What they did not show, however, is that the compression of these cycles in time was associated with a curious epidemiological phenomenon: a reversing traveling wave of outbreak along the corridor of Highway 11. The first wave traveled eastward from Hearst to Cochrane 1989-1995, and the second wave traveled westward from Cochrane to Hearst 1996-2004 (Fig. 6, top). Between these two locations, in the zone of overlap at Kapuskasing-Smooth Rock Falls, trembling aspen host trees, having very little respite from defoliation during the middle years 1993-1996, were exceptionally vulnerable to sudden dieback and decline (Fig. 6, bottom).

Traveling waves of insect outbreak are of interest to population ecologists because they are one of the dynamic features predicted by theoreticians to occur in spatially extended predator-prey systems (Hassell et al. 1994, Bjornstad et al. 2002). However, this particular traveling wave appears to be different from those that occur in simple theoretical models in that it reversed direction very suddenly. It is not yet clear why this outbreak progressed in the unusual way that it did, but this question is being investigated through population

<sup>1</sup> Note we are not suggesting that 3 years of defoliation is an ecological threshold parameter in a nonlinear mortality function. On the contrary, we expect the mortality function is a smooth linear function of the degree and duration of defoliation, and that three years is merely the amount of defoliation required to surpass an arithmetic impact detectability threshold (unpublished data, D. Marchand, F. Lorenzetti, Y. Mauffette, Y. Bergeron).



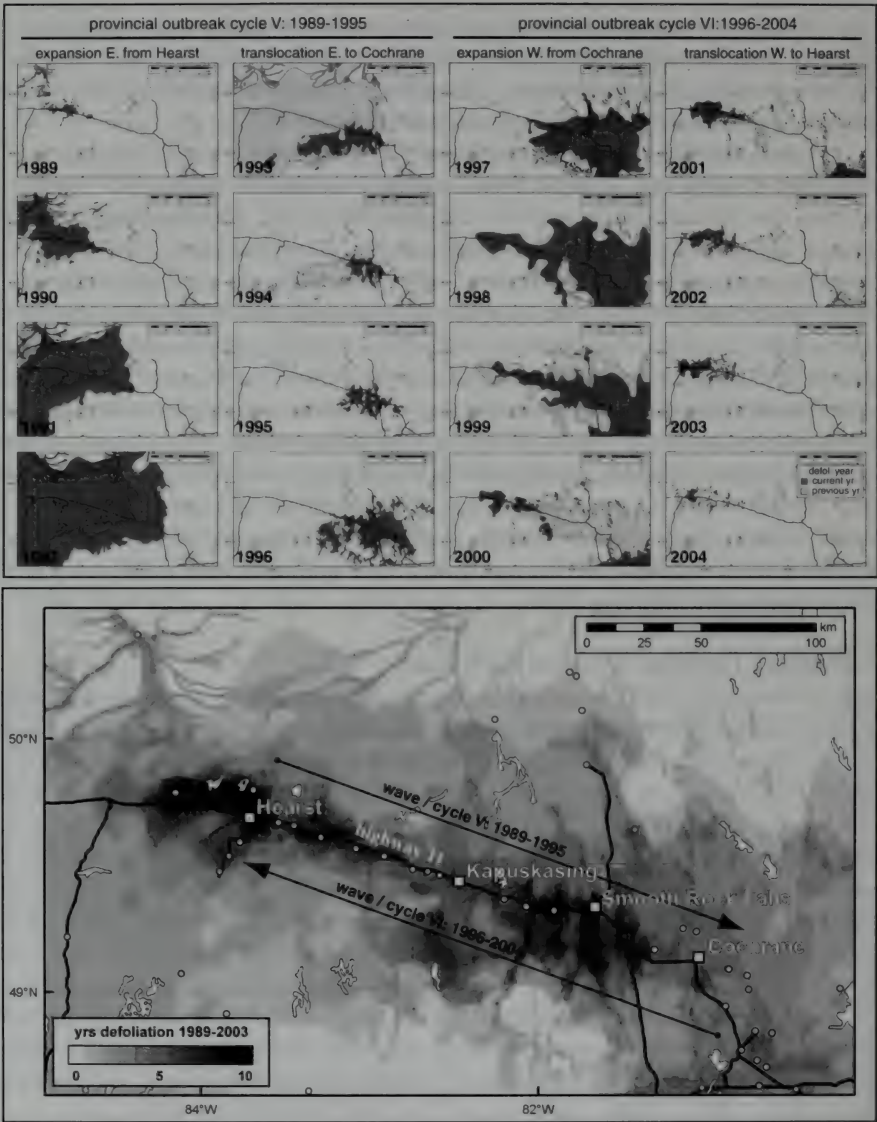


FIGURE 6. Progression of defoliation during outbreak cycles V (1989-1995) and VI (1996-2004) in northern Ontario. Top: annual displacement of defoliation between years. Outbreak V, originating at Hearst, expanded and shifted eastward toward Cochrane, while outbreak VI, originating at Cochrane, expanded and shifted westward toward Hearst. Bottom: cumulative distribution of defoliation, 1989-2003. Although Hearst and Smooth Rock Falls both experienced ~9 years of defoliation over the two outbreak cycles, it was at Smooth Rock Falls where the two population cycles occurred in such rapid succession that there was little or no respite in defoliation. This is where the highest levels of aspen decline were observed (Candau et al. 2002).

studies and simulation modeling. What we can state, however, is a clear prediction that a complex dynamic of this type can be expected to be replayed in the future. Meanwhile, it would be worthwhile trying to determine how much aspen decline might have happened in response to the overlapping waves of tent caterpillar outbreak that occurred in the boreal and aspen parkland regions of Alberta in the early and late 1980s, respectively (Cooke 2001).

Finally, this exposé reveals a demarcation problem in our attempts to quantify outbreak duration. Recalling that 1994 was the year between cycles V and VI where province-wide defoliation reached a minimum (Fig. 2), we see now that this was actually the peak year of defoliation in the out-of-phase regional oscillation at Smooth Rock Falls (Fig. 6, top). Thus our provincially defined time-frame led to a regional-scale truncation of the out-of-phase outbreak at Smooth Rock Falls, such that this single regional outbreak was treated as two separate provincial outbreaks. Outbreak duration in this instance was therefore underestimated. Estimation error due to imperfect demarcation (deciding where one outbreak cycle stops and another one starts) is clearly unavoidable when cycle synchronization is imperfect.

#### **4. Variability in Outbreak Duration, Extent and Timing**

Outbreaks appear to be more variable in extent in Quebec than in Ontario, although this inference is based on a limited sample of only six cycles. Excluding the unusually extensive outbreak cycle II from the Quebec data, it would appear that the two provinces exhibit similar levels of variability. However it is not clear that such dismissal is warranted. Although cycle II was unusually extensive in Quebec, it was also the most extensive outbreak on record in Ontario. Before discounting cycle II in Quebec as an outlier, it is important to know if this anomaly might be explained by some persistent feature of the environment, such as a more variable climate in Quebec.

There does not appear to be any evidence that the range of forest tent caterpillar outbreaks in east-central Canada is shifting gradually northward in response to a climate warming trend (Fig. 3). Thus it would be premature to suggest that the decline of aspen in northern Ontario in the late 1990s was facilitated by climate warming. This system does not appear to be responding as strongly to climate change as, say, mountain pine beetle in western Canada (Carroll et al. 2004). On the other hand, given that (i) weather is not the only driver of the system's dynamics, and (ii) the 20th century global warming trend has been punctuated by brief cooling phases (Smith and Reynolds 2005), it may be quite difficult to estimate the marginal effects of climate change, especially with such a short, stochastic time-series. Indeed, one of the reasons we have tried to be as quantitative as possible in estimating outbreak duration is so that future studies looking at this question will have a solid baseline from which to start. Although tent caterpillar outbreaks may last as long as 3-6 years in some areas, this is neither precise enough nor accurate enough an estimate to serve as a baseline for future studies looking at potential shifts in dynamics in response to climatic and landscape change.

The reason we are keen to continue pursuing this hypothesis is because of regional differences in outbreak occurrence, with outbreak duration being twice as variable in Quebec as in Ontario. Looking back at the provincial defoliation time-series of Fig. 2., it is striking how cycles III, IV, and V appear to have been interrupted in the early stages of



development in Quebec, but not in Ontario, hence the asynchronous pattern of outbreak between the two regions during that time-period. In fact, the years of cycle interruption can be identified with some precision: 1963, 1976, 1989. It would not surprise us if it should turn out that these cycles were interrupted by cold spring or winter weather, as described by Cooke and Roland (2003), for it certainly appears that the insect's distribution in Quebec may be strongly limited by a combination of climate and topography (Cooke and Lorenzetti 2006). It is for this reason that we expect climatic change may eventually be found to have some influence on long-term tent caterpillar dynamics. However additional research on the relationship between insect survival and weather is required before the hypothesis can be refined to the point of a specific prediction.

## Conclusion

This note is not intended to discount other figures published in the literature, but merely to put them in context. We want to emphasize that although most forest tent caterpillar outbreaks do not last longer than 1-2 years, those rare ones that do last longer than 2 years tend to result in "significant" (i.e. readily detectable and/or economically important) mortality. The reason that forest tent caterpillars are generally thought of as benign insects is not because they are incapable of destroying a forest. Rather, it is because outbreaks are typically terminated before they reach their third year. As our analysis indicates, there are always small areas where outbreaks linger on for 4 years or longer.

Our second major point is that although it is desirable to be able to forecast population oscillations in time and space, from a forestry perspective it is not particularly useful to be able to predict cycle timing across the bulk of the outbreak range, when it is the number of years of defoliation in excess of three that determines whether or not forests survive. The real challenge lies in predicting precisely when, where and under what circumstances the number of years of defoliation will exceed the three-year threshold.

Just as meteorologists have difficulty in predicting extreme weather events, so entomologists are likely to find it challenging to obtain any success in predicting extreme entomological events. Predicting animal population fluctuations is an imprecise science. Predicting which of these fluctuations are likely to result in anomalously severe and prolonged population eruptions is going to require continuing research into the fundamentals of population dynamics. Understanding the forces that lead to imperfect synchronization of cyclic population fluctuations is one promising avenue for determining when and where waves of outbreak may overlap to produce unusually long-lasting infestations capable of causing large-scale forest decline.

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## NEW RECORDS OF PIPUNCULIDAE ATTACKING PROCONIINE SHARPSHOOTERS (AUCHENORRHYNCHA: CICADELLIDAE: PROCONIINI)

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### Abstract

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Five records of Pipunculidae (Diptera) attacking proconiine sharpshooters (Auchenorrhyncha: Cicadellidae) are documented here for the first time. *Eudorylas alternatus* (Cresson) is documented as a parasitoid of *Cuerna obtusa* Oman and Beamer and *Oncometopia orbona* (Fabricius) is recorded as being attacked by an apparently undescribed species of *Eudorylas* (Pipunculidae). Records of unidentified pipunculid larvae are also recorded from *Cuerna kaloostiani* Nielson, *Cuerna curvata* Oman & Beamer, and *Cuerna* sp. near *striata* (Walker) – *septentrionalis* (Walker). We describe these observations, summarize the data for them and explore the potential of Pipunculidae as biological control agents for pest proconiines such as glassy-winged sharpshooter (*Homalodisca vitripennis* (Germar)). We also reveal the utility of DNA barcoding for identifying pipunculid larvae.

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### Introduction

With the exception of the big-headed fly genus *Nephrocerus* Zetterstedt which attack crane fly adults (Tipulidae), pipunculids are parasitoids of leafhoppers and planthoppers (Hemiptera: Auchenorrhyncha). They typically attack second instar larvae, although some parasitize adults (Waloff and Jervis 1987). Big-headed flies are found in almost every terrestrial habitat world-wide including agricultural ecosystems. Their larvae develop fully within their host, typically emerging from the dorsum of the abdomen of adult hosts after a rapid development. Hosts are usually rendered sterile or are killed by these parasitoids. Larvae normally pupariate in the leaf litter or soil. Development is variable with multivoltine species typically eclosing from the puparium within a few days to weeks and univoltine species overwintering in the substrate (Waloff 1980; Skevington and Marshall

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1997). The effects of pipunculid parasitization on planthoppers and leafhoppers have been documented by numerous scientists, most recently by May (1979), Chandra (1980), Waloff (1980), Lauterer (1981), Huq (1984, 1986a, 1986b), Ylonen and Raatikainen (1984), Yano (1985), and Skevington and Marshall (1997). Parasitized hosts are sometimes recognizable by their swollen abdomen and sluggish movements.

Recorded rates of parasitism vary from fractions of a percent to nearly 100 percent in local populations. For example, Hartung and Severin (1915) found *Circulifer tenellus* (Baker) (beet leafhopper, Cicadellidae) with up to 47% parasitism by two pipunculid species and Skevington and Marshall (1997) recorded parasitism rates of *Cuerna striata* by *Eudorylas* sp. near *alternatus* to be as high as 89%. Despite the importance of pipunculids as parasitoids, few rearing records exist for Pipunculidae, particularly in North America (Skevington and Marshall 1997). Data on host ranges are available for more than 52 European species of Pipunculidae (Skevington and Marshall 1997) while in the Nearctic Region only 16 species have received such documentation (Skevington and Marshall 1997; Moya-Raygoza et al. 2004; Koenig and Young 2007).

The potential value of Pipunculidae for biological control has stimulated some work on the bionomics of this family. For example, research into the control of the potato leafhopper, *Empoasca fabae* (Harris), a major pest of alfalfa in mid-western and eastern USA and Canada, involved exploration within Europe for natural enemies to be introduced to the United States (Jervis 1992). *Chalarus* specimens were reared for this effort but apparently were never released. Similarly, European species of *Chalarus* were considered for introduction into New Zealand for control of Froggatt's apple leafhopper, *Edwardsiana crataegi* (Douglas), populations of which are insecticide resistant (Jervis 1992). A release was never made because of concerns about adding yet another foreign species to the New Zealand fauna (pers. comm. M. De Meyer).

We decided to investigate the potential of these flies as parasitoids of Glassy-winged Sharpshooter (GWSS, *Homalodisca vitripennis* (Germar) (Cicadellidae, Proconiini)) in 2005. This species is native to the southeastern USA and northeastern Mexico, from Augusta, Georgia to Leesburg, Florida, west to Val Verde and Edwards counties in Texas, south to Mexico (Turner and Pollard 1959; Triapitsyn and Phillips 2000). It has become a serious pest of grapes in California where it was introduced in 1989 (Sorensen and Gill 1996; Hoddle 2004). Glassy-winged sharpshooters are effective vectors of *Xylella fastidiosa* Wells et al. (Eubacteria), the causative agent of Pierce's Disease in grapes, which has severely damaged vineyards in southern and central California (Hoddle 2004). Considerable effort has been expended to find egg parasitoids of GWSS and other pest leafhoppers, but little effort to date has been made to study their nymphal parasitoids (Goolsby and Setamou 2005; Irwin and Hoddle 2005; Pilkington et al. 2005). Finding a larval parasitoid for GWSS would be a great advance in potential biological control programs for the species. Although we have not discovered such a parasitoid, the discovery of several pipunculid parasitoids (described below) attacking related proconiine species is encouraging.

## Methods and Materials

Adult pipunculids and leafhoppers were either killed with cyanide and pinned or collected into 100% alcohol. Specimens are deposited in the Canadian National Collection of Insects, Arachnids and Nematodes (CNC) and the Illinois Natural History Survey Collection (INHS). The CNC specimens are all labelled with a unique number (either in the format JSS # *n* or CNCD # *n*). Pipunculid larvae were collected into 70% alcohol (RR) or 100% alcohol (JHS). Voucher data for the material used in this study are available in Appendix 1.

Field work contributing to this study was conducted by two teams. Roman Rakitov collected the Arizona specimens while conducting general fieldwork there in 2003. John Goolsby coordinated fieldwork in Texas where his team was searching for potential biological control candidates for GWSS. When possible, leafhoppers were killed and dissected in the lab to search for parasitoids. When no lab facilities were available, leafhoppers were examined in the field for evidence of parasitism. Although leafhoppers that are parasitized by third instar pipunculids may be recognized in the field by their sluggish behaviour and swollen abdomens, we found no behavioural changes in cicadellids parasitized by first instar larvae. Dissection of a random series of leafhoppers in the field (by removing their abdomens and squeezing out the contents) thus allowed discovery of parasitized populations of leafhoppers. Even though very small, first instar pipunculids are easy to see as they crawl around.

Pipunculid larvae and adults collected in the survey were sequenced in an effort to match the identity of the immatures with the adult specimens. DNA was extracted and a 658 base pair fragment of the COI gene (now referred to as *cox1* in the 'barcoding' literature) was amplified using the primer pair LCO1490 (5'-GGTCAACAAATCATAAAGATATTGG-3') and HCO2198 (5'-TAAACTTCAGGGTGACCAAAAAATCA-3') (Folmer et al. 1994). Methods used follow Hebert et al. (2003). Relevant sequences were deposited in GenBank (Appendix 1).

Parsimony and neighbour-joining analyses were performed with PAUP\* (Swofford 2001). *Chalarus* sp. was defined as the outgroup for all analyses, as this is the putative basal genus of Pipunculidae (Rafael and De Meyer 1996; Skevington and Yeates 2000). The heuristic search procedure was used with stepwise-addition and 100 random replications. The heuristic search option was used with tree bisection-reconnection branch swapping, MULPARS, and random addition of taxa. Multistate characters were treated as non-additive.



## Results and Discussion

### Arizona

Between 13 and 18 April 2003, 33 *Eudorylas alternatus* puparia were obtained by R. Rakitov from pipunculid larvae developing within *Cuernia obtusa* in Arizona (Appendix 1). From these puparia, 19 adult pipunculids (10 females, 9 males) were reared. The leafhoppers were collected in forests of *Pinus edulis* and *P. ponderosa*. Note that the identification of these flies is tentative, despite being based on examination of the *E. alternatus* holotype. Confirmation will only be possible in the context of a complete revision of *Eudorylas*. The best current key to Nearctic eudorylines (Hardy 1943) does not work and over half of the species in the genus are undescribed (Skevington unpublished data). These flies appear to be conspecific with the flies reared from *Cuernia striata* in Ontario, Canada (Skevington and Marshall 1997). Although there is minor genitalic variation, their *cox1* sequences differ by only 0.5%. This is typical of genetic distances among species of Pipunculidae (Skevington et al. 2007).

Rakitov (personal communication) also reports records of pipunculized specimens of *Cuernia kaloostiani* from Arizona, *Cuernia curvata* from California, and *Cuernia* sp. near *striata* – *septentrionalis* from Utah. The parasitized cicadellids and extracted pipunculid larvae supporting these records are in the INHS collection. These pipunculids are likely also species of Eudorylini, but further research is needed to corroborate this hypothesis.

### Texas

On 20 October 2005, we dissected two first instar pipunculid larvae out of adult *Oncometopia orbona* at Yegua Creek, Texas (from ten *O. orbona* that were dissected). All efforts to rear this species of pipunculid from additional leafhoppers failed. Larval pipunculids are unidentifiable to species and in most cases, even to genus. In an effort to identify the larvae, we extracted DNA from one specimen and sequenced *cox1*. The generic identity of this larva was hypothesized based on phylogenetic placement of this sequence within a large matrix being prepared for a paper on the phylogeny of Pipunculidae (Skevington et al. unpublished data). Parsimony analysis using this dataset supported the placement of the larva as a member of the genus *Eudorylas* (the closest relative, *E. alternatus*, was 14.2% different based on pairwise analysis). This generic identification was expected, given that the other two identified pipunculids recorded as attacking proconiines were species of *Eudorylas*. Based on this discovery, we added 54 morphospecies of Eudorylini from the southern USA to the *cox1* dataset and found a match (specimen CNC3333) – the uncorrected pairwise distance between the two specimens is 0.6%, within the range of typical intraspecific genetic distances for pipunculids (Skevington et al. 2007). Assigning a name to this fly continues to be a problem. It cannot be identified with existing keys and will only be named in the context of a planned revision of the Eudorylini (Skevington, in prep). What we have learned though is where this species is likely to occur. Comparing CNC3333 with other female pipunculids in the Canadian National Collection of Insects and the United States National Museum collection, turned up five specimens of this species (listed as *Eudorylas* sp. TX8 in Appendix 1). As a result, we now know that this species occurs from College Station and Yegua Creek, Texas (Houston area) to Greenville, Mississippi, and appears to be at least bivoltine. Flight times are from April to May and September.

This example illustrates the power of DNA barcoding to associate immature stages with adults. It also illustrates how important it is to continue to work towards modern revisions of these flies. One of us (JHS) has been routinely DNA barcoding all of the species that he includes in revisions for five years (Skevington 2005b; Skevington 2006; Skevington and Földvári 2007; Skevington and Kehlmaier 2008), but a concerted effort is clearly needed to barcode as many species of adult pipunculids as possible. Doing so will open up research on biological control and facilitate ecological studies of these important flies.

Given the oligophagous nature of most pipunculids, we speculate that the species attacking *O. orbona* will also be found in *H. vitripennis* as both of these proconiines occur in the same habitats at the same time of year. Further research is warranted to collect, rear and evaluate this species of pipunculid as a potential biological control agent of *H. vitripennis* where it is invasive in California. Revision of Nearctic Eudorylini is also clearly a priority. It is likely that over 200 species occur in the Nearctic Region and only 38 valid species are currently described (Skevington 2005a). Most of these are not identifiable using current resources.

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**Appendix 1 – Material Examined (Voucher data)**

**Pipunculidae: Pipunculinae: Eudorylini: *Eudorylas alternatus* (Cresson):** USA, AZ, Coconino Co., 2.5 miles S Tusayan, “10X” Campground, 35°56'16.3" N, 112°07'48.7" W, R. Rakitov, 9□, 10□, 11 puparia, 3 third instar larvae, collected in *Pinus edulis* & *Pinus ponderosa* forest, host collection date 11.iv.2003, pupation dates 13-18.iv.2003, adult emergence dates 9-13.v.2003, host *Cuerna obtusa* Oman and Beamer, JSS# 13848-13849 (CNC), 13850 (INHS), 13851 – 3 legs removed for sequencing – GenBank # DQ349219, 13852-13854 (CNC), 13855 (INHS), 13856-13869, 13871-13881 (CNC).

***Eudorylas sp. nr. alternatus* (Cresson)** Canada, ON, Sideroad 25, 5 km SE Arkell, 1□, host collection date 27.iv.1993, pupation dates 1.v.1993, adult emergence date 20.v.2003, host *Cuerna striata* Walker, JSS#12590 (CNC) – 3 legs removed for sequencing – GenBank # DQ349219.

***Eudorylas sp. TX8: larvae:*** USA, TX, Lee Co., Yegua Creek, 30°17'28" N, 96°15'39" W, 82 m, J. Skevington, 20.x.2005, 2 first instar larvae (one per host), host *Oncometopia orbona* (Fabricius) adults (one voucher JSS#16947 listed below), JSS#16853, one larva destroyed for sequencing – GenBank # DQ337627 (CNC); **adult females:** USA, TX, Brazos Co., College Station, Lick Creek Park, 30°38' N, 96°20' W, 17. Iv. 2006, Malaise trap, R. A. Wharton, CNCD3333 – GenBank # FJ860147 (CNC); USA, MS, Lafayette Co., F. M. Hull, v.1951, CNCD4914, iv.-v.1946, CNCD4914 (CNC); MS, Greenville, 11.ix.1922 (2 specimens), CNCD4916-7 (CNC).

**Cicadellidae: Cicadellinae: Proconiini: *Oncometopia orbona* (Fabricius):** USA, TX, Lee Co., Yegua Creek, 30°17'28" N, 96°15'39" W, 82 m, J. Skevington, 20.x.2005, host of first instar Eudorylini larva (larva destroyed for sequencing), 1 adult □, JSS#16947 (CNC).

## POPULATION DYNAMICS OF *HARMONIA AXYRIDIS* AND *APHIS GLYCINES* IN NIAGARA PENINSULA SOYBEAN FIELDS AND VINEYARDS

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### Abstract

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Multicoloured Asian lady beetle (*Harmonia axyridis*) is an occasional pest of wine and juice grapes in vineyards throughout northeastern North America. In late season, beetles aggregate on grape clusters immediately before harvest, and are difficult and expensive to remove before processing. Outbreaks of *H. axyridis* are thought to be related to soybean aphid (*Aphis glycines*) populations. Heavy infestations of aphids occur late in the season on soybeans and can sustain large numbers of *H. axyridis*. Each summer from 2004 to 2006, 23-29 soybean fields along the escarpment of the Niagara Peninsula were monitored each week for soybean aphid infestation, and all life stages of *H. axyridis* were recorded. Where substantial populations of *A. glycines* were found, larvae and adults of *H. axyridis* soon followed. Severity of *H. axyridis* infestation in vineyards was still high even when *A. glycines* populations were reduced by insecticides in soybean fields in 2005. Outbreaks of *H. axyridis* in vineyards are correlated with substantial populations of soybean aphid that occur early in the season. Outbreak populations of *H. axyridis* in vineyards were observed in years where *A. glycines* eggs were not abundant on overwintering hosts, thus *H. axyridis* density appears to be negatively correlated with numbers of overwintering *A. glycines* eggs on its primary host, *Rhamnus cathartica*. A model of interaction between the two species is proposed.

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### Introduction

Multicoloured Asian lady beetle (*Harmonia axyridis* (Pallas), Coleoptera: Coccinellidae) is an alien invasive predator important in southern Ontario agro-ecosystems. *Harmonia axyridis* is an occasional pest of wine and juice grapes in vineyards throughout northeastern North America (Ker and Carter 2004). Like most coccinellids, adults and larvae of *H. axyridis* are predacious, with a diet consisting primarily of aphids and other

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soft-bodied insects, supplemented by small amounts of plant material (Hodek 1973). In the Niagara Peninsula region of southern Ontario, late season aggregations of adults have been observed on ripening grape clusters immediately before harvest (Ker and Carter 2004). During processing, beetles may be crushed into the slurry of skins and stems (Pickering 2004). Beetles are difficult and expensive to remove from grape clusters before processing, and if they are not removed before processing the grapes, alkaloids secreted by beetles as defensive chemicals affect the flavour of wines and juices (Koch 2003, Pickering 2004).

Insects inevitably are present at grape harvest, but usually in low enough numbers that their presence does not affect quality or flavour of wine. *Harmonia axyridis* presents a problem because the beetle itself has a very unpleasant taste and odour, due to a bitter defensive chemical, 2-isopropyl-3-methoxypyrazine (IPMP), present in its haemolymph (Pickering 2004). The limit of detection by humans of IPMP in water is in the range of two parts per trillion (Pickering 2004).

The Niagara Peninsula region of Ontario is an intensely cultivated area home to 94% of Ontario's grape industry, with an annual farm gate value of \$60 million (Gardner et al. 2006). Approximately 40 million litres of wine are produced in Ontario each year, generating \$438 million in retail sales (Grape Growers of Ontario 2007). This region also has large areas devoted to field crops located above the escarpment and south of grape growing areas. Most vineyards have fields of soybeans planted within 1-2 km of their location (Fig. 1).

Outbreaks of *H. axyridis* in grapes may be related to infestations of soybean aphid (*Aphis glycines* Matsumura). Though *H. axyridis* has been present since 1994 in southern Ontario, large populations of *H. axyridis* were not observed in Ontario vineyards until 2001, coinciding with the arrival of *A. glycines* (Ker and Carter 2004). *Harmonia axyridis* is an important natural predator of *A. glycines* in its native range (Koch 2003, Wu et al. 2004). First identified in North America in 2000 in Wisconsin, *A. glycines* is now a severe pest of cultivated soybean (*Glycine max* Merrill) in 21 American states and three Canadian provinces (Ragsdale et al. 2004). *Aphis glycines* undergoes a heteroecious, holocyclic life cycle, alternating between parthenogenic reproduction on its secondary summer host, *G. max*, and sexual reproduction and overwintering on a primary woody winter host, buckthorn (*Rhamnus* spp.) (Ragsdale et al. 2004, Voegtlin et al. 2004). Typically, *A. glycines* occurs as a sexual morph on foliage of *Rhamnus* spp. in autumn, as an egg on buds of *Rhamnus* spp. in winter, as an asexually reproducing female on *Rhamnus* spp. in spring, and as an asexually reproducing female in cultivated soybean in summer (Ragsdale et al. 2004, Voegtlin et al. 2004).

Ample populations of aphids can support large numbers of *H. axyridis* (Fox et al. 2004), and there is anecdotal evidence that in years favouring heavy infestation of *A. glycines*, heavy infestations of *H. axyridis* occur in vineyards. A biennial cyclical pattern of outbreak years seems to be emerging for both *H. axyridis* in grapes and *A. glycines* in soybeans, in which economically damaging infestations of both species occurred in 2001, 2003, 2005, and 2007, but only spot infestations were observed in 2002, 2004, 2006, and 2008 (Bahlai 2007, Glemser, E. et al., unpub. data)

It is possible that soybean fields near to Niagara vineyards serve as a reservoir for *H. axyridis*. Starting near the middle of the growing season, *H. axyridis* might reproduce in

soybean fields, and feed as adults and larvae on aphids. When aphids move to overwintering sites, beetles seeking alternate food sources in the absence of aphids, might move directly to nearby vineyards filled with ripening grapes. If this relationship holds true, numbers of *H. axyridis* observed in vineyards should correspond to numbers of beetles observed in soybean fields just before soybean leaf senescence occurs.

From June to September in 2004, 2005 and 2006, we monitored 23-29 soybean fields weekly for *A. glycines* infestation and for all life stages of *H. axyridis* in the Regional Municipality of Niagara, ON. The purpose of this study was threefold:

- 1) to provide scouting information for Niagara area soybean growers regarding *A. glycines* infestation levels, and to estimate numbers of *H. axyridis* for Ontario grape growers and vintners,
- 2) to examine whether population assessments of *H. axyridis* in soybean fields correspond with infestations of the beetle in nearby vineyards,
- 3) to test the hypothesis that soybean fields act as reservoirs for *H. axyridis* before beetles infest vineyards.

## Methods and Materials

During the growing seasons of 2004-2006, soybean fields were selected along the edge of the Niagara Escarpment in proximity to vineyards from Grimsby (43.2°N, 79.7°W) to Niagara-on-the-Lake (43.2°N, 79.1°W) (Fig. 1). Nearby vineyards generally were located on the “bench” below the escarpment, in the northern portion of the peninsula, 2-8 km from the shore of Lake Ontario. Soybean fields selected were generally located to the immediate southwest of vineyards, and within a 5 km radius. In 2004, 23 soybean fields were monitored each week; in 2005 and 2006, 29 and 28 fields were monitored each week, respectively.

Monitoring consisted of sampling 10 sites randomly selected within a soybean field. At each site, three soybean plants were assessed for soybean aphid populations using the following rating scale (after Difonzo and Hines 2002). Aphid populations were assessed on stems and on the middle leaflets of the lowest, middle and top trifoliate leaves. The following rating system was applied to each part of the plant: 0 = No aphids present (not infested), 1 = 1-10 aphids present (low infestation), 2 = 11-25 aphids present (moderate infestation), 3 = 26-100 aphids present (high infestation), and 4 = 100+ aphids present (extreme infestation). Ratings for all plant parts were averaged, providing a total infestation rating out of four for each plant. These ratings were averaged by field and provided an average infestation score for the fields in a particular area.

For each of the plants assessed, the number of larval, pupal and adult *H. axyridis* present on the plant were counted. These numbers were averaged by field and geographical region, and reported in units of average number of individuals per soybean plant.

Each site was monitored once weekly, commencing on July 13 in 2004, June 22 in 2005, and June 23 in 2006. Monitoring continued until soybean leaf drop occurred in all observation fields in September. Population data for fields in particular areas were compared with *H. axyridis* infestation levels in nearby corresponding vineyards and with counts of overwintering eggs of *A. glycines* as described in Welsman et al. (2007).



Data for the regression analyses were organized by observations in a given week. Regression analyses were performed on population data using PROC GLM (SAS Institute, Cary, NC) to determine whether counts of larvae, pupae and adults of *H. axyridis* would correlate over time with infestations of *A. glycines*, or if a one or two week delay in interval would provide a better statistical relationship. A significance level of  $\alpha=0.05$  was used for all analyses.

## Results

In 2004, *A. glycines* populations reached moderate infestation levels in soybean fields across Niagara in late August (Fig. 2). None of the observation fields had insecticides applied at this time, because at the time this study was performed treatment was not recommended for soybean aphid control after the R5 ('beginning seed') plant stage is reached (Baute 2007). Infestation rankings reached an average of 0.25 in the week of August 12, 2004 (Table 1). Sharp increases in aphid infestation occurred in the two weeks following August 24, with populations peaking by September 7 in all observation fields. Numbers of *H. axyridis* larvae followed a similar growth and peak pattern, with jumps in their population growth correlating with increases in aphid infestation ( $R^2 = 0.88$ ,  $p < 0.0001$ ) (Table 2, Fig. 2). Abundance of pupae correlated significantly with aphid infestation after one week ( $R^2 = 0.53$ ,  $p = 0.006$ ), with adult beetles following at two weeks after aphid infestation increase ( $R^2 = 0.70$ ,  $p = 0.002$ ) (Table 2, Fig. 2).

In 2005, an average rating of 0.25 was first recorded on July 19, over three weeks earlier than was observed in 2004 (Table 1). Earlier infestation of soybean fields by *A. glycines* and rapid increasing severity of infestation in early summer (Fig. 2) resulted in 28 of 29 observation fields being sprayed with cyhalothrin-lambda (Matador 120E\*, Syngenta Crop Protection Canada) or dimethoate (Cygon 480\* and Lagon 480EC\*, Cheminova Canada) (OMAFRA 2005) to control populations in the weeks of August 9 and 16, 2005. Aphid infestation across the peninsula peaked in these weeks, and subsequently decreased for the rest of the season in most of the observation fields (Fig. 2). Populations of *H. axyridis* began to increase in observation fields early in the season, correlating with aphid infestation levels (Table 2), but sharply declined after the application of insecticides (Fig. 2). The relationship between aphid infestation and larvae or pupae counts after a delay of one week in 2005 was weaker than in 2004 ( $R^2 = 0.42$ ,  $p = 0.020$  for larvae,  $R^2 = 0.44$ ,  $p = 0.012$  for pupae) (Table 2).

In 2006, very low aphid infestation and very few *H. axyridis* were observed in Niagara Peninsula soybean fields (Fig. 2). Aphid infestation density did not reach a rating of 0.25 until August 22, 2006 (Table 1). Counts of larvae of *H. axyridis* were observed to correlate well with aphid infestations in soybean fields, but occurred one week and two weeks after the corresponding aphid population estimate (Table 2). The relationship between beetle and aphid densities was significant for all three temporal relationships examined (Table 2).



FIGURE 1: Locations of observation soybean fields and collaborating vineyards in 2004, 2005 and 2006, in the vicinity of Vineland, ON. Each observation field was monitored once weekly during the soybean growing season, to determine soybean aphid infestation level and multicoloured Asian ladybeetle counts. Observation fields were typically located at the top of the Niagara escarpment, to the southwest of collaborating vineyards. Map adapted from the Regional Municipality of Niagara Public Works Department, Operational Services Division.



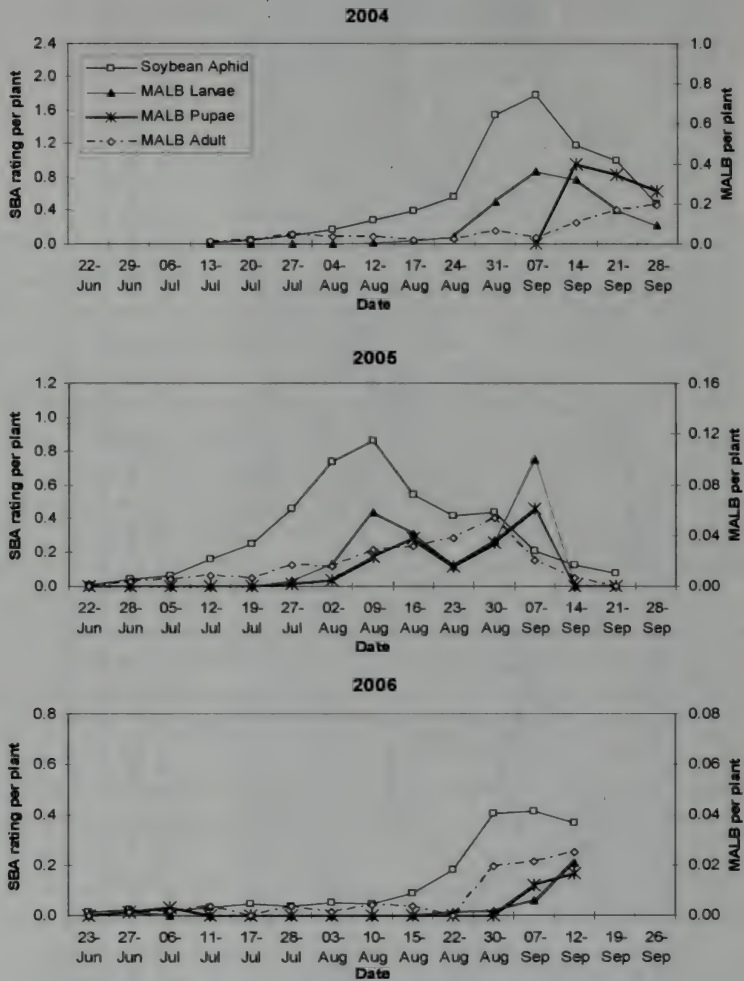


FIGURE 2: Soybean aphid (SBA) infestation rating and multicoloured Asian ladybeetle (MALB) counts for soybean fields in the Niagara Peninsula region of southern Ontario in 2004, 2005 and 2006. Area-wide averages are shown. A sample of thirty soybean plants in observations field were monitored weekly. SBA ratings were performed by examining the stem and upper, middle and lower trifoliates of each plant and rating each portion of the plant on a scale of 0 to 4, where 0=No aphids present, 1=1-10 aphids present, 2=11-25 aphids present, 3=26-100 aphids present, 4=100+ aphids present. Raw counts of MALB adults, pupae and larvae were performed for each plant. Note: scales of graphs differ to preserve detail when average aphid infestation levels and ladybeetle counts are lower in 2005 and 2006.

TABLE 1: Soybean aphid (SBA) populations in soybean fields in the Niagara Peninsula region of southern Ontario, 2004-2006. Dates when an average of one aphid colony per plant was first observed and when soybean leaf drop occurred, a description of the peak aphid population, is provided. Counts of aphid eggs subsequently observed in overwintering sites and infestation levels of multicoloured Asian ladybeetle (MALB) in vineyards for each year are included.

Year	Date rating of 0.25 reached	SBA peak	Date of soybean leaf drop	Total SBA eggs observed on <i>R. cathartica</i> <sup>1</sup>	MALB infestation in vineyards <sup>2</sup>
2004	12-Aug-04	Moderate, after pod set, no chemical control required	28-Sep-04	5585	Low: spot infestations (raw data not available)
2005	19-Jul-05	Moderate, before pod set, chemical control widely applied	21-Sep-05	4	High: widespread infestation (896 adult MALB observed in sampling period)
2006	22-Aug-06	Low, after pod set, no chemical control required	12-Sep-06	250	Low: spot infestations (105 adult MALB observed in sampling period)

<sup>1</sup> Welsman et al. (2007): soybean aphid eggs collected from 10 cm buckthorn twig segments (N=1200) in autumn near Guelph, ON.  
<sup>2</sup> Kevin Ker, Ker Crop Management Services, personal communication. Assessments completed by counting number of MALB observed per meter of grape vine in commercial vineyards.

TABLE 2: Linear regression of observed populations of various life stages of multicoloured Asian ladybeetle (MALB) on soybean aphid infestation scores in soybean fields in the Niagara peninsula region of southern Ontario, 2004-2006. Counts of each life stage of MALB were correlated to soybean aphid infestation observed concurrently, one, and two weeks before.

		MALB life stages							
		Larvae			Pupae			Adults	
Year	Week	R <sup>2</sup>	P		R <sup>2</sup>	P		R <sup>2</sup>	P
2004	0	0.88	< 0.0001	*	0.09	0.340		0.06	0.420
	1	0.83	< 0.0001	*	0.53	0.006	*	0.30	0.080
	2	0.33	0.080		0.91	< 0.0001	*	0.70	0.002 *
2005	0	0.18	0.130		0.12	0.230		0.40	0.020
	1	0.42	0.020	*	0.44	0.012	*	0.50	0.007 *
	2	0.19	0.150		0.33	0.050		0.56	0.005 *
2006	0	0.41	0.200		0.45	0.012	*	0.84	< 0.0001 *
	1	0.70	0.001	*	0.82	< 0.0001	*	0.86	< 0.0001
	2	0.98	< 0.0001	*	0.85	< 0.0001	*	0.71	0.001 *

\* Significant at  $\alpha=0.05$



## Discussion

To date, a biennial cycle of outbreak years of both *H. axyridis* and *A. glycines* has consistently occurred in the Niagara (Glemser, E. et al, unpub. data). As was observed in 2001 and 2003, in the present study, high numbers of aphids appeared early in the 2005 growing season, and high lady beetle numbers appeared in vineyards later in the season (Table 1). In 2004 and 2006, as in 2002, low or moderate late-season soybean aphid infestations occurred, and only low infestations of *H. axyridis* were observed in vineyards (Table 1). Infestation by *H. axyridis* in vineyards in a given year did not necessarily correlate with observed numbers of ladybeetles in soybean fields immediately before leaf senescence. More *H. axyridis* individuals in total were observed in soybeans in 2004, when only spot infestations of the beetle were observed in vineyards, than in 2005, when vineyard infestation by *H. axyridis* was reported to be much higher. This provides evidence against the hypothesis that abundance of ladybeetles in vineyards results entirely from abundance of *A. glycines* and that beetles move directly from soybeans to ripening grapes.

The application of insecticides to most of our observation soybean fields in 2005 confounded our results considerably. The insecticides cyhalothrin-lambda (Matador 120E<sup>®</sup>, Syngenta Crop Protection Canada), a pyrethroid, and two formulations of dimethoate (Cygon 480<sup>®</sup> and Lagon 480EC<sup>®</sup>, Cheminova Canada), an organophosphate, are registered for use in controlling soybean aphid in Ontario soybeans (OMAFRA 2005). Pyrethroids are extremely toxic to larvae of *H. axyridis* (Youn et al. 2003) and unpublished field trials suggest they have a repellent effect on adults (K. Ker, personal communication). In leaf-dip trials, organophosphorous pesticides applied at normal rates resulted in low survivorship of all life stages of *H. axyridis* (Youn et al. 2003).

This decline in abundance of *H. axyridis* in soybean fields observed after insecticide application may occur for several reasons: 1) the insecticide is toxic to *H. axyridis*, 2) the insecticide may act as a repellent to adults of *H. axyridis*, so that they disperse from the field and new migrants avoid the field, or 3) the sudden drop in aphid abundance results in insufficient aphid populations for the induction of oviposition by *H. axyridis*, so that beetles disperse to locate other populations of insects on which to feed. A combination of these explanations likely leads to the observed population decline of *H. axyridis*. By early August, when insecticides are applied if needed to soybeans for control of *A. glycines* in the Niagara region, we have observed other aphid species supporting feeding populations of *H. axyridis* on common weeds such as lamb's quarters (*Chenopodium album* L.) or milk vetch (*Vicia cracca* L.). If insecticides repel surviving adults of *H. axyridis*, and there are not sufficient aphid populations in soybean fields, beetles will move out of soybean and forage on abundant populations of other aphid species occurring in weedy areas, woodlots or orchards. This dispersal of *H. axyridis* from soybean fields confounds monitoring of ladybeetle population numbers because large numbers of *H. axyridis* are likely present outside soybean fields in late summer, and at that time of year, populations of *A. glycines* may no longer have as much influence on the population growth of *H. axyridis*.

The exact relationship between outbreaks of *H. axyridis* in vineyards and outbreaks of *A. glycines* in soybeans can only be speculated upon at this time, but the two may be related. Grape harvest in Ontario usually begins in the last week of September, and continues until the middle of October, except for vineyards where grapes are destined for

use in late-harvest or ice wines. In most years, there is a two to three week difference in time between soybean leaf senescence and the beginning of grape harvest. It is unknown where *H. axyridis* populations which were previously residing in soybean are located during this two to three week period. It is possible that *H. axyridis* simply uses grapes as a food source immediately prior to overwintering, as sugars in grapes may be more efficiently converted to stored energy in the fat body of the insect than proteins from aphids (Hodek 1973, Denlinger 2005). In this scenario, grapes may be a preferred food of *H. axyridis*. However, if ripe grapes are preferred over aphids by *H. axyridis*, beetles would be observed in vineyards in every year, and not just when aphids are scarce.

A possible explanation may be found in the overwintering habits of *A. glycines*. As day length decreases and soybean leaves senesce, *A. glycines* migrates to the overwintering host, buckthorn (*Rhamnus* spp.) (Voegtlin et al. 2004). Mating occurs on this host and eggs are laid on buckthorn buds (Ragsdale et al. 2004). In Ontario, oviposition by *A. glycines* typically occurs by late October (Welsman et al. 2007). In this study, during years when *A. glycines* infestation remained below economic threshold (i.e. 2004 and 2006), moderate populations of aphids were observed in soybean fields immediately prior to soybean plant senescence. In a companion study in the same years Welsman et al. (2007), found that high numbers of overwintering eggs of *A. glycines* were found in *Rhamnus cathartica* stands in Ontario (Table 1). Conversely, in 2005, when soybean fields monitored in this study had heavy, early infestations of *A. glycines*, very few overwintering eggs were observed using the same protocols as in 2004 and 2006 (Table 1).

We propose that interactions between *A. glycines* and *H. axyridis* on the primary host of *A. glycines* in spring and again after soybean senescence on the overwintering host of *A. glycines*, play a larger role in dictating the abundance of *H. axyridis* in vineyards than do late summer interactions in soybean, as previously speculated. Large populations of *A. glycines* on its overwintering host may “kick-start” or “distract” *H. axyridis*, depending on the time of year at which it occurs. Abundance of *A. glycines* early in the season initiates (kick-starts) population growth of *H. axyridis*. Abundances of *A. glycines* on *R. cathartica* in autumn function to draw *H. axyridis* away (distract) from vineyards in the fall (Fig. 3).

In spring, *H. axyridis* are usually found on *Rhamnus cathartica* almost immediately after bud swell in mid to late April, feeding on aphids, and mating (Bahlai et al. 2007, Bahlai et al. 2008). *Rhamnus cathartica* leaves begins to grow earlier than most other woody plants in southern Ontario agroecosystems and egg hatch of *A. glycines* coincides with this event (Bahlai et al. 2007), so it is likely that *A. glycines* on *R. cathartica* represent one of the earliest abundant food sources for *H. axyridis* (Fig. 3A iii). Predation by coccinellids, predatory bugs, and syrphid larvae and parasitism by braconid and aphelinid wasps have been shown to affect the population dynamics of soybean aphid in soybean fields (eg: Fox et al. 2004, Heimpel et al. 2004, Fox et al. 2005, Desneux et al. 2006, Brosius et al. 2007). Welsman et al. (2007) found that predation, rather than parasitism, slows the growth of these early-season populations of *A. glycines* occurring on buckthorn, and attributed most of the mortality to coccinellids. Oviposition among coccinellids typically occurs in the presence of food (Hodek 1973) so it is reasonable to speculate that abundance of *A. glycines* in April may allow *H. axyridis* to oviposit earlier in the season than would have occurred otherwise, effectively ‘kick-starting’ the population growth of *H. axyridis*.

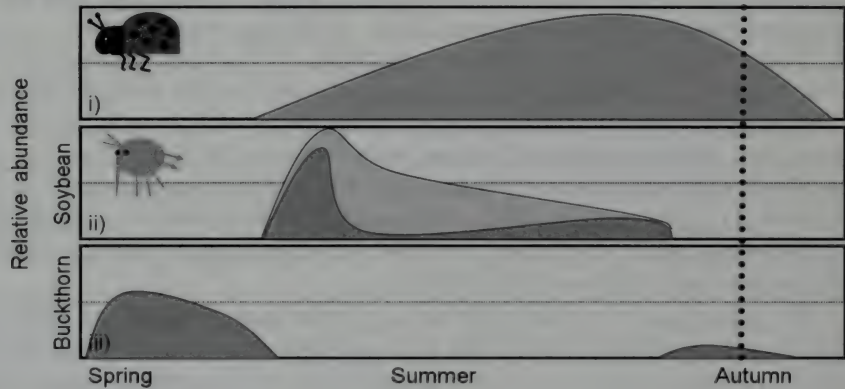
In early summer, *A. glycines* migrates to its summer host, soybean. When large



numbers of aphids are observed in soybean, increasing numbers of larvae and adults of *H. axyridis* are observed soon after. Predation can cause a crash in aphid populations by the end of the season (Fig. 3A ii, shaded curve) (Fox et al. 2004) . Alternatively, insecticides may be applied to soybean fields for aphid control, causing aphid numbers to decline in soybean fields (Fig. 3A ii, solid curve).

In mid-September, *A. glycines* migrates back to its overwintering host, *R. cathartica*, where it remains feeding on foliage until oviposition occurs, usually around the time the shrub drops its leaves in late October (Welsman et al. 2007). *Rhamnus cathartica* retains its leaves later than many other plants in southern Ontario agroecosystems, so this

A) High year (kick-start)



B) Moderate-low year (distract)

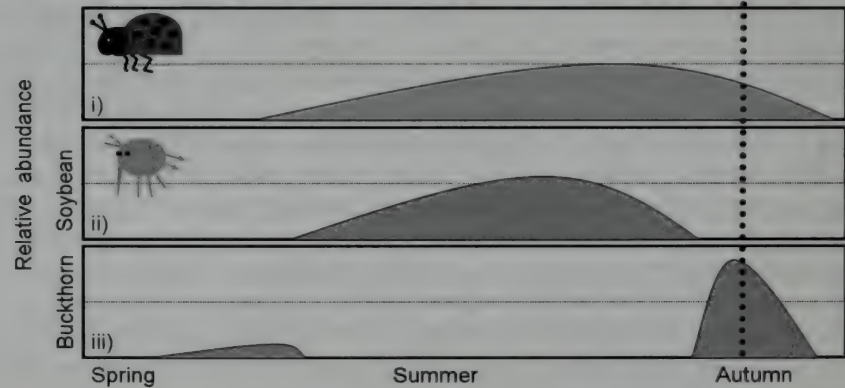


FIGURE 3: Hypothetical “kick-start- distract” model of interaction between *Harmonia axyridis* and *Aphis glycines*. In this scenario, early season abundances of *A. glycines* on buckthorn ‘kick-start’ population growth of *H. axyridis*, and late season abundances of *A. glycines* ‘distract’ *H. axyridis* from grapes until after harvest. A) Kick-start year, B) Distract year. Illustrated for each year are hypothetical abundances of i) *H. axyridis*, ii) *A. glycines* on soybean and iii) *A. glycines* on buckthorn. Dotted vertical lines represent grape harvest.

host may represent the last reservoir of aphid populations before winter within the Niagara region agroecosystem. In years when *A. glycines* is abundant on its overwintering host, *H. axyridis* typically is observed with the aphid (Bahlai et al. 2008), and is 'distracted' from ripening grapes in vineyards (Fig. 3 B iii).

In years when *A. glycines* is not abundant on buckthorn, *H. axyridis* aggregates in large numbers in Niagara Peninsula area vineyards (Fig. 3A i, iii) (Welsman et al. 2007). When aphids are scarce, beetles may move to ripening grapes because volatiles released by fermentation of fruit may be similar to volatiles associated with aphid honeydew (Bahlai et al. 2008). If this is the case, ripe grape odour could 'trick' *H. axyridis* into foraging in vineyards for aphids, or simply act as a cue for the location of a 'next best' food source.

In years when a high number of aphid eggs had been observed in the previous winter, both *A. glycines* and *H. axyridis* were observed at higher numbers in soybean in July. Higher counts of *H. axyridis* were observed in late July in 2005 than in 2004 and 2006. However, when insecticides were applied to these fields in August 2005, numbers of *H. axyridis*, like aphid infestations, decreased immediately, and persisted at low levels for the remainder of the season (Fig. 2). Yet we observed substantial numbers of *H. axyridis* feeding on aphids living on weeds in naturalized and semi-naturalized areas adjacent to our observation fields in mid to late August of 2005 and large numbers of *H. axyridis* were observed in vineyards that year. In years where only spot infestations of *H. axyridis* were observed in vineyards (i.e. 2004 and 2006), abundance of *A. glycines* on the overwintering host was observed. In these years, lower numbers of *H. axyridis* could have been sated by large populations of aphids preparing to mate and oviposit on buckthorn.

This kick-start/distract model for the interaction of *H. axyridis* with *A. glycines*, combined with insecticide application practices, may help to explain the biennial cycle of infestation for both *A. glycines* and *H. axyridis*. To develop an effective integrated pest management strategy to control vineyard infestations of *H. axyridis*, several specific areas of inquiry should be pursued. Population monitoring of these beetles and their prey should be continued to gain data regarding numbers and distribution; monitoring of *A. glycines* and *H. axyridis* should continue in Niagara Peninsula area soybean fields, and should be expanded to include populations of aphids in other crops and weeds in late summer. This monitoring could provide information about agroecosystems in which *H. axyridis* occurs in late summer. This may provide an early warning for potential vineyard infestations. Because the interactions between *A. glycines* and *H. axyridis* appear to be consistently following a biennial cycle, additional population data can be used to refine predictions of when and where outbreaks of these two species will occur, and under what conditions.

## Acknowledgements

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## NEW RECORD OF THE ASIATIC GARDEN BEETLE, *MALADERA CASTANEA* (ARROW), IN ATLANTIC CANADA

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### Scientific Note

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The Asiatic garden beetle, *Maladera castanea* (Arrow) (Coleoptera: Scarabaeidae), was first named by Arrow in the genus *Autoserica* in 1913, moved to the genus *Aserica* in 1927 by Arrow, and then moved by Pope to genus *Maladera* in 1961 (Evans and Smith 2005). *Maladera castanea* is endemic to the Russian Far East, Japan, North Korea, and South Korea (Ahrens 2006). It was first collected in North America near Rutherford, New Jersey in 1921 (Hallock 1929, 1930, 1936) but has been studied sporadically since 1927. It is known to have established along the eastern seaboard from Massachusetts to South Carolina, west to Pennsylvania and Ohio (Hallock 1936; Potter 1998). In those regions it is generally a minor pest of turfgrass, ornamentals and some vegetables. However, *M. castanea* may cause serious economic damage, is known to feed on more than 100 host plants, and may be locally abundant, particularly in weedy or abandoned areas (Hallock 1936; Koppenhofer and Fuzy 2003; Tashiro 1987).

*Maladera castanea* appears to have been first collected in Canada in Saint-Armand, Québec, in 1996 (Chantal 2003). Specimens were subsequently found in multiple locations of southern Québec (Bostanian et al. 2003; Chantal 2003). Here, we document the collection of *M. castanea* from Cumberland County, Nova Scotia, which we believe is the first record of this insect in Atlantic Canada.

Collections occurred in a commercial, wild (syn. "lowbush") blueberry (*Vaccinium angustifolium* Ait.) growing area near Fox River, Cumberland Co., Nova Scotia (N45° 40.83', W64° 53.43'). One particular field was described by the producer as a "flag-ship" field, historically producing high numbers of berries. For reasons that were unknown to the grower, production in the field had decreased and attempts to rejuvenate the field through conventional fertilizer, pesticide and irrigation practices were unsuccessful. Soil samples (approximately 20 x 20 x 20 cm) were collected with a spade shovel on 21 May 2003, 17 July 2007, and in early June 2008, from areas in fields with poor plant growth, near the farm road and along a hedgerow of trees that separated fields. Samples were sifted through in the field or later in the laboratory and collected larvae were stored in 70% ethanol.

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An unexpectedly large number of Scarabaeidae larvae were present in several of the soil samples, particularly those adjacent to patches of grass and sedge, common weeds in wild blueberry fields. Formal counts of larvae from each sample were not conducted, but several grubs were collected in 2003, around 40 in 2007, and several in 2008. We also observed that many blueberry plant roots from samples containing these Scarabaeidae larvae had suffered feeding damage, with extensive girdling and destruction of fibrous roots and root hairs, as well as root necrosis as a result of this feeding (Fig. 1).



FIGURE 1. Damage to wild (lowbush) blueberry roots where *M. castanea* larvae were found in Fox River, Nova Scotia, 2003. Photo: R.E.L. Rogers, Wildwood Labs Inc.



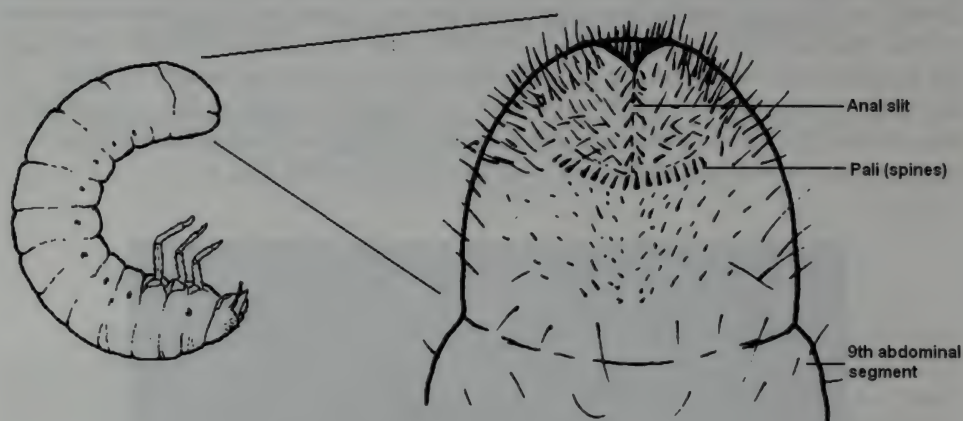


FIGURE 2. Rastral pattern on the 10th abdominal segment of a *M. castanea* larva, illustrating the characteristic longitudinal anal slit and crescent-shaped transverse row of spines (adapted from Tashiro 1987; with permission, NY State Agricultural Experiment Station).

Larval specimens were confirmed as *M. castanea* by R.E.L.R and G.C.C. Voucher specimens have been deposited in the A. D. Pickett Entomology Museum at the Nova Scotia Agricultural College and the Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, ON. *Maladera castanea* larvae can be most easily distinguished from other scarabaeid turfgrass feeders such as the Japanese beetle, *Popillia japonica* Newman, the oriental beetle, *Exomala* (syn. *Anomala*) *orientalis* Waterhouse, masked chafers, *Cyclocephala* spp., and European chafer, *Rhizotrogus majalis* (Rhazoumowsky), by the characteristic positioning of the anal slit and arrangement of spines, hairs and bare spaces on the raster of the terminal (tenth) abdominal segment. A single, transverse row of spines in a crescent shape is the most noticeable character (Fig. 2, 3a), and whereas the anal slit may be transverse or Y-shaped in related species, it is essentially longitudinal in *M. castanea* (Reding and Klein 2006; Tashiro 1987). Other distinguishing larval characters include very small claws of the metathoracic legs, as compared to the pro- and mesothoracic legs, and a light-coloured, enlarged bulbous stipe of the maxilla (Fig. 3b). *Maladera castanea* larvae are smaller than those of *P. japonica*, *E. orientalis*, and *R. majalis*, with full-grown third instars being approximately 19 mm long. *Maladera castanea* adults were not collected, but they are 8-11 mm long, dull chestnut-brown, with a velvety, slight iridescent sheen (Tashiro 1987). Adult beetles generally conceal themselves in moist soil at the base of food plants and grasses during the day. They fly only at night, but are highly attracted to lights, a behaviour that has proved useful in collecting or monitoring for *M. castanea* (Tashiro 1987).

Soil samples were not collected throughout the blueberry fields in question, and therefore it is not possible to correlate *M. castanea* with the progressively poorer berry yields generated. However, white grubs, including *M. castanea*, are increasingly important pests of highbush blueberries (Alm et al. 1999; Cowles 2005; Wise et al. 2007), other *Vaccinium* spp. (Koppenhofer et al. 2008; Wenninger and Averill 2006), strawberries (LaMondia et

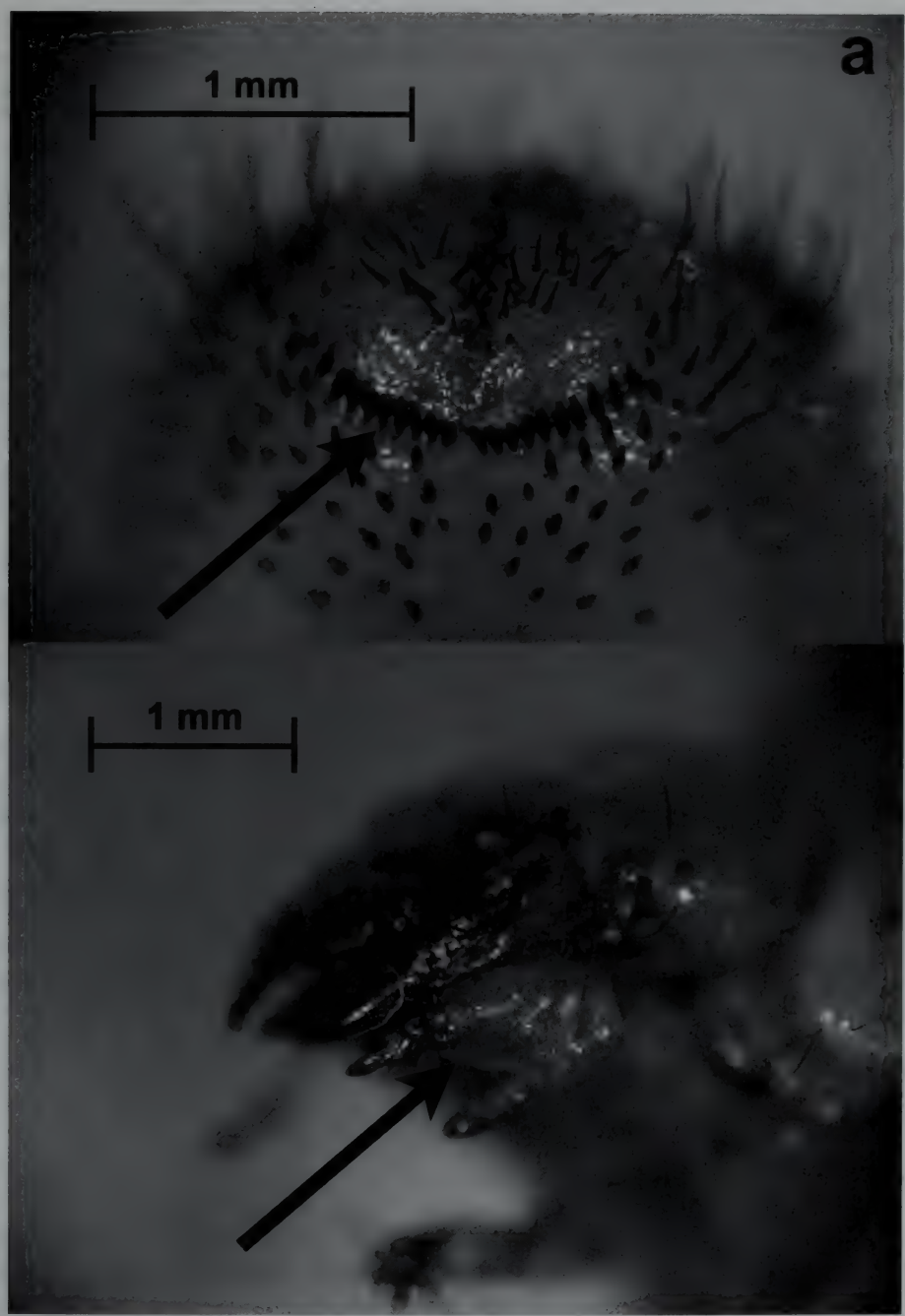


FIGURE 3. *Maladera castanea* larva from Fox River, Nova Scotia, 2008, (a) rastral pattern on the 10th abdominal segment and (b) head illustrating the enlarged bulbous stipe of the maxilla. Photos: R.E.L. Rogers, Wildwood Labs Inc.



al. 2002), turf (Koppenhofer and Fuzy 2003), and other crops, ornamentals and perennials (Tashiro 1987). Hallock (1936) reported that adults and/or larvae may cause considerable injury to many vegetables, including beets, carrots, corn, parsnips, peppers, and turnips, but that larvae were almost always more numerous in grassy areas overgrown with weeds, particularly in the presence of hawkweed (the preferred oviposition site), goldenrod, wild asters and, to a lesser extent, sorrel. Indeed, we found *M. castanea* feeding on *V. angustifolium* in patches next to a high density of grasses and other weeds. Further, being an unfamiliar, subterranean root feeder with few natural enemies (Tashiro 1987), there is potential for undetected population growth.

Although it is unknown how *M. castanea* became established in the Fox River area, the producer revealed that there is occasional back-and-forth transport of farm machinery (e.g. tractors, harvesters) from operations in the state of Maine where the beetle is known to exist, suggesting cross-border transport. Alternatively, this *M. castanea* record could simply be the product of natural expansion throughout North America. With recent intensive efforts of C.G. Majka and colleagues to document Coleoptera occurrence in the Maritimes (<http://www.chebucto.ns.ca/Environment/NHR/PDF/index.html>), it is somewhat surprising that *M. castanea* has not been found earlier or elsewhere. Whether the geographic range of *M. castanea* in this region is poorly understood or if the beetle is of sporadic occurrence is unclear. Future work will attempt to map the distribution of *M. castanea* throughout Nova Scotia.

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## GROWING PAINS: HOW THE BIRTH OF THE ENTOMOLOGICAL SOCIETY OF CANADA AFFECTED THE IDENTITY OF THE ENTOMOLOGICAL SOCIETY OF ONTARIO

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### Special Contribution

*J. ent. Soc. Ont.* 140: 49-56

The histories of the Entomological Societies of Ontario and Canada are inextricably entwined. Both lay claim to the same founding story and early historical narrative<sup>1</sup>, yet also maintain their identities as distinct organizations. Superficially, the history is simple: the Entomological Society of Canada (ESC) was founded in 1863, and changed its name to the Entomological Society of Ontario (ESO) in 1871. The name change reflected the geopolitical changes of the period (Ontario was one half of the Province of Canada when the society was formed and part of the rapidly growing Dominion of Canada when the name changed), as well as a pledge of annual financial support from the government of Ontario received in that year (Saunders 1883). Despite its new name the ESO continued to operate as a national body for almost eighty years, with branches across the country. However, in the period after the Second World War a number of members began to suggest that it was time for the formation of a truly national society. Thus, in 1950 the ESC was founded and began to fulfill its chief function: "to serve as a national society and as the parent association of, or as the link between, the other entomological societies in Canada" (Ozburn 1950).

The foundation of the new ESC effectively resulted in the demotion of the ESO to a regional society. Although other histories written on the subject indicate that this was a smooth transition (Spencer 1964; Holland 1966; Connor 1982), in this paper I argue that the appropriation of their role by the national society caused a great deal of conflict between the two societies as the members of the ESO were forced to reevaluate the purpose and identity of the Ontario society. I will show how this anxiety was manifested in disagreements between the parent society and its offspring over a number of matters in the period between 1950 and 1963, as well as how the ESO began to redefine its identity in the years after 1963. Specifically, I will examine the conflicts and issues surrounding the disposition of shared assets and the organization of annual general meetings, as well as the societies' publications. This paper will also provide the first written history of the ESO in the years after the foundation of the ESC. It is not my intention to stir up old controversies or animosity, but to provide a written record of this period in the history of both societies – a record that I hope will prove to be both informative and interesting to its readers.

<sup>1</sup> See for example the web pages for each society, which contain the same description of their origins: *About the ESO*, online, no date, available at: <http://www.entsocont.com/> (accessed: 1 May, 2008) and *History of the Entomological Society of Canada*, online, no date, available at: <http://esc-sec.org/> (accessed: 1 May, 2008)

## A Complicated Relationship

The foundation of the ESC created a society whose affairs were so entangled with those of the ESO that, much like a divorce, a legal agreement was required to sort out which society was responsible for what. The Instrument of Agreement, developed after much negotiation between the two societies, was signed on 1 November 1954 and applied retroactively to the activities of the previous three years (Ozburn and Baker 1954). The Instrument formalized a number of the arrangements that had been vaguely outlined in the original motion approving the formation of the ESC (Ozburn 1950). These included the point that the ESO should retain possession of its library, a collection of some significance accumulated throughout the life of the Society, as well as the periodicals received in exchange for the societies' publications. It also defined the understanding that membership in the ESC was compulsory for members joining the ESO. Its main purpose, however, was to clarify the responsibilities related to the joint publication of The Canadian Entomologist, an internationally recognized journal which had been published continuously on a monthly basis since 1868. Although it seemed clear that a journal with that title should be published by a national society, after having published it for more than 80 years the ESO was not ready to give it up completely.

By the end of the 1950s, the Instrument of Agreement, whose articles had been designed to help the ESC get off the ground, was causing a great deal of friction between the two societies and was in serious need of revision. In 1957, inspired by a conflict over the distribution of shared membership fees, a special meeting of the ESO Board of Directors was called to address some of the issues that had been "smouldering for years" (Dustan 1957a) between the two societies. The ESO found itself in a difficult position; they no longer wanted to be "tied to the Canada Society" (Dustan 1957b), but they also did not want to lose their share in The Canadian Entomologist. By 1958, however, the ESO was forced to admit that "for all intents and purposes the Canadian society had assumed full control" (Peterson 1960) of the journal. A revised Instrument of Agreement was developed in 1960, in which the ESO relinquished its rights as publisher of the journal but retained certain residual rights (Peterson et al. 1960). From the ESO's perspective, chief among these residual rights was the request that their historical role be acknowledged in perpetuity on the inside cover of The Canadian Entomologist; the particular wording of this clause was the subject of much negotiation (Peterson 1960).

It is likely that much of the conflict between the ESC and the ESO was due to their dual claim to the history of one of the oldest scientific societies in North America; it wasn't clear which, if either, had more of a right to it. This ambiguity stems from the fact that, although the organization had Ontario in its name for seventy-nine years before the founding of the national society, it spent the first eight years of its life with the designation of Entomological Society of Canada. Most histories of the subject written by entomologists take the stance that "though provincial in name, the Society was always national in outlook and objectives" (Holland 1966) and claim the whole record as that of the ESC. The only analysis written by a historian puts forward the opposite opinion; that the ESO was effectively only ever a regional society and that there was no "truly and officially national, professional scientific society" (Connor 1982) of entomology until 1960 when the ESC assumed full control of The Canadian Entomologist. Regardless of which viewpoint



is correct, it seems likely that “the frictions and conflictions of interest” (Dustan 1957a) between the two societies were not only result of the ESO being upset by the assumption of its national role by the ESC, but also by what it saw as the appropriation of its history.

## One Hundred Years of Entomology

Shortly after the revision of the agreement between the ESO and the ESC, the societies were faced with another challenge to their harmonious existence: the celebration of the 100th Annual Meeting of the Society. In previous years, the annual meeting had been one of the most important traditions for the ESO. Special exhibits and scrapbooks were put together for the 25th, 50th, 60th, and 75th Annual Meetings<sup>2</sup>, large celebrations were thrown for many of these events, including invitations to and participation by representatives of societies and institutions across Canada, the United States, and even the United Kingdom and Europe<sup>3</sup>. When the ESC was formed, it was decided that its annual meeting would always be held in conjunction with one of the provincial societies – the former branches of the ESO (Ozburn 1950). In its first ten years of existence as an independent society, the ESC held joint annual meetings with the ESO four times. In light of both this and their shared history, it is not surprising that the ESO and the ESC chose to co-organize the 100th annual meeting in 1963. However, given the already established disagreements and resentments that were brewing, it seems inevitable that the situation would end badly.

Celebration of the centennial anniversary became a matter of intense debate and controversy between the two societies, highlighting the underlying tensions between them. On the surface, much of the debate was about the location of the meeting. At the 1960 Annual Meeting of the ESO, the membership voted to hold the centennial meeting in Guelph, a place that many felt was “inseparably linked with the growth and development of the Society” (McBain Cameron 1962). The ESC centennial committee, however, felt that the meeting should be held in Ottawa, a “location in keeping with the importance of the event” (Holland 1961). The centennial committee presented and won support for their case at the 1961 ESC Annual Meeting in Quebec. The matter went back to the ESO membership at their 1961 Annual Meeting, and after “rather extensive discussion” (Holland 1961), ESO voted to keep the Guelph decision. This resulted in a flurry of angry letters between the board members of both societies, and a special ballot sent out to the membership asking which decision they felt should stand – Guelph or Ottawa. The results of the ballot were dramatic; the decision came in at 80 votes for Guelph and 81 votes for Ottawa, with two votes for Guelph coming in after the deadline had passed (Wressell 1962b). The centennial committee got its way and the meeting took place in Ottawa. The closeness of the vote, however, indicated that beneath the “whole contentious mess” (Wressell 1962a) of the location of the centennial

<sup>2</sup> Programs of many of the Annual Meetings are available in the Entomological Society of Ontario Collection, University of Guelph Archival and Special Collections, Boxes 9, 16 and 20.

<sup>3</sup> For example, the scrapbook for the 50th anniversary celebrations included telegrams and letters of congratulations from 35 groups and institutions, and attendees of the meeting included representatives from an additional 56 different societies, institutes, departments, etc. Entomological Society of Ontario Collection, University of Guelph Archival and Special Collections, Box 19.

meeting, a deeper divergence between the two societies had formed.

## Modern Times

In the decades following the centennial celebration, the ESO seems to have become more resigned to its “now wholly provincial” (Holland 1961) role. As the ESC went on to address matters of national policy in science<sup>4</sup>, the ESO became more concerned with keeping their society solvent and relevant. In 1969, the Society gave away one of its most valuable assets, the library it had negotiated to keep from the ESC, to the University of Guelph. It did this despite the original efforts it had gone through to hold on to the library, and despite the fact that it was “worth at least \$50,000” (McBain Cameron 1969), because the space the library was occupying in the Biology buildings was needed, and the ESO could not afford to move them elsewhere (Hérne 1968). The ESO also became more interested in letting the ESC take on tasks that it might previously have handled. For example, in 1985 the Public Education committee decided to stop pursuing the idea of creating a brochure to promote careers in entomology because of the “feeling” that it should be “developed by the national society” (Anonymous 1985). Perhaps most surprising, especially in contrast to the issues of the centennial celebration, is that the 125th annual meeting of the ESO seems to have passed with a minimum of fanfare. It was not held jointly with the ESC, and the ESO secretary remarked in the January newsletter that the meeting had “a smaller turnout than usual” (Smith 1989) of only seventy attendees. Although there was a speaker at the meeting who reviewed the contribution of the ESO over the years, the President reported that “financial support was not found for a proposal to prepare a history of the Society” (Jaques 1989).

Financial problems became more critical for the ESO as it was forced to turn its secondary publication, The Annual Report, into the primary journal of the Society after letting go of The Canadian Entomologist for good. The Annual Report had never been as widely read as The Canadian Entomologist; its continued publication was carried out in large part to fulfill an obligation to the Ontario government. One of the stipulations of the 1871 grant from the Ontario Council of Agriculture was that the society must furnish an annual report on “insects injurious or beneficial to agriculture” (Saunders 1883). For this reason, the papers published in the Report were often less representative of the range of papers presented at the annual meeting than they were focused on economic and applied issues of entomology. In an effort to change this image of the journal and boost readership, in 1959 the ESO changed the name of the periodical to the Proceedings of the Entomological Society of Ontario and began actively to solicit papers of all types. It is not clear how closely the two events are related, but shortly after the name change, the Ontario Department of Agriculture proposed to withdraw its financial support (Boyce 1968). The ESO was then faced with the problem of supporting the cost of publication itself, which

<sup>4</sup> For example, the ESC became heavily involved in the Biological Council of Canada in the 1970s and provided a number of briefs to the Federal Government on various issues such as the teaching of Biology in Canadian Universities and the publication of Canadian Science Journals, see Boxes 1 and 2 in the Entomological Society of Ontario Collection, University of Guelph Archival and Special Collections.



left them wondering if The Proceedings were “worth the struggle”, especially “since most entomologists publish elsewhere anyway” (Salkeld 1968).

Although the ESO had difficulty maintaining the relevance of and interest in its publication over the past thirty years, it persevered, in large part due to the fact that the Board has been “reluctant to break a series” (Ellis 1984). Once the society was responsible for the cost of the publication, it was forced to institute a page charge policy, requiring authors to pay for each page of their articles. This meant fewer manuscripts were put forward, and that one of the tasks of the editor was to constantly badger the membership for submissions (eg. Ellis 1982, Prévost 2002, Richards 2006). Fewer submissions made it harder to stick to the annual publication schedule; a variety of creative means to catch up were employed, including publishing in one volume all of the papers presented at annual meeting symposia (Anonymous 1985b; Kevan 1987; Bolter 1990), as well as dedicating volumes to particular entomologists (Anonymous 1985a; Richards 2007)<sup>5</sup>. In 1989, severe financial troubles obligated the ESO to solicit and accept donations from a variety of sources, including a large pesticide company, in order to continue publication of the journal (Kinoshita 1989). The most recent efforts to increase the profile of the publication included renaming it again in 2003, this time as the Journal of the Entomological Society of Ontario (Prévost 2003), as well as making it available online (Richards 2006). During all this time, “discontinuing The Proceedings” was “out of the question” (Marshall 1989), an attitude which emphasizes the ESO’s particular commitment to its history.

While much of the evident tension between the two societies appears to have dissipated after the 1963 meeting, the ESC continued to experience problems with the ESO that it did not encounter with other provincial societies, specifically related to the organization of joint annual meetings. One past president of the ESC did not hesitate to point out Ontario as an example of the “problems [that] do exist in some regions” (Cooper 1976). It was perhaps for this reason that the ESC executive voted in 1977 to hold a joint meeting with the Entomological Society of America in 1982 in Toronto without the support of the ESO, a decision that the Ontario society felt left them “out in the cold” (Smith 1977). Finances and annual meetings were another issue. Beginning with the 1963 meeting, the ESC attempted to establish a procedure for the sharing of profits and losses related to joint annual meetings (Munroe 1962). As of 2005, the ESC was still trying to formalize this process. Although most of the other provincial societies have abided by the “rather loose arrangement” (Shore 2005) of sharing half the profits of joint annual meetings with the national society, the ESO has not always been cooperative; after the 2001 joint annual meeting in Niagara Falls the ESO declined to give any of the profits to the ESC (Hunt 2001), causing much consternation in the national society. However, after the 2008 joint annual meeting in Ottawa the ESO gave 51% of the profits to the ESC (C. Scott-Dupree, personal communication), a sign of the generally amiable relationship that currently exists between the two societies.

<sup>5</sup> Interestingly, volume 116 (1985) as well as volumes 137 and 138 (2006 & 2007) were all dedicated to D.H. Pengelly, former secretary and treasurer of the ESO. As far as I am aware, no other person has had volumes of the Proceedings / Journal dedicated to them.

## Conclusion

All previous histories of the ESO and ESC have ended their narratives at or shortly after the celebration of the centennial; in reading them one gets the impression that the creation of the national society had been the ultimate goal of the ESO. This paper has shown that this was not the case, that it took at least a decade for the members of the ESO to adjust to their altered role as a provincial society and that occasional remnants of this strain remain in evidence to this day. Furthermore, the shared history and subsequently tumultuous division of the two societies created a distinctive connection between them that deserves to be celebrated and explored. This investigation should be of interest to those wishing to produce more complete histories as the 150th anniversary of organized entomology in Canada approaches.

## Acknowledgments

The assistance of the staff at the archives, McLaughlin Library, University of Guelph, in providing access and photocopies of archival material is greatly appreciated. Information and suggestions provided by Kevin Barber (Treasurer, ESO) and Sandy Smith (Former Secretary and President of the ESO) were also helpful. Finally, I thank Steve Walker for useful comments on an earlier version of this manuscript.

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## BOOK REVIEW

**Field Guide to the Dragonflies and Damselflies of Algonquin Provincial Park and the Surrounding Area.** By Colin D. Jones, Andrea Kingsley, Peter Burke and Matt Holder. Algonquin Field Guide Series, published by The Friends of Algonquin Park. 263 pp. ISBN 978-1-894993-29-6 (Soft cover: October 2008). \$28.95 CAN.

This book is billed as a comprehensive field guide to the dragonflies and damselflies found in Algonquin Provincial Park and surrounding area, but it is much, much more than that. The coverage actually extends across south-central Ontario and into southwestern Quebec, and includes 135 out of the provincial total of 172 Odonata species. The detailed, full-colour illustrations set a new standard for the illustration of field guides with stunning watercolours showing the intricate colours of males, females and variants in brilliant detail.

The introductory text is excellent, with clear and nicely illustrated treatments of Odonata morphology, behaviour, and life cycle, but the real strength of this book is in the profusely illustrated and carefully organized identification tools that lead the reader to informative treatments of each species. There are no keys, but instead the authors have used tables and charts illustrated by line drawings, watercolors and some photographs. The nine families involved are easily separated using three colour pages devoted to diagnosing the families. Within each family there are pages combining line-drawings of the male and female genitalic characters that define the species. These are of tremendous value in confirming the identification of difficult species, but it is unlikely that the average user will refer to them very often; most users will instead identify their odonate finds by thumbing through the profusely illustrated species accounts in search of a "match". Useful diagnostic characters are highlighted or indicated with arrows and captions, and actual size is indicated with a silhouette. Once a match is located, the reader is provided with a "description" (a one-paragraph diagnosis), a very useful discussion of similar species, and information about habitat, behaviour, abundance, and distribution. Flight period is given both in the text and in graphical form along the heading for each species.

This is a wonderful book that I think belongs on the shelf of every entomologist and naturalist in Ontario. Not only is it well organized, beautifully illustrated and informative, it is also well-packaged. At 14 x 21 cm, it is just the right size to fit into a jacket pocket or the outside pouch of a day pack, and it looks water-resistant and sturdy enough to hold up to a bit of bashing. My main criticism of the book centers on what might be perceived by some as its main strength, which is the degree to which it is focused on Algonquin Park.

As far as I know this book can only be purchased from bookstores or from Algonquin's website ([www.algonquinpark.on.ca](http://www.algonquinpark.on.ca)), which is likely to limit its readership despite the current popularity of Odonata among naturalists. The popular online bookseller Amazon.ca currently lists 36 books on dragonflies and damselflies (it is for good reason that dragonflies have been described as the "new butterflies"), but *Dragonflies and Damselflies of Algonquin Provincial Park* is not among them. This combination of limited availability and a local-sounding title is likely to limit the number of readers with interests outside the Algonquin area, which is unfortunate since this is a tremendously useful guide for most of Ontario, and indeed much of northeastern North America. I'm looking forward to a later edition, or a follow-up version including all 172 Ontario Odonata species!

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